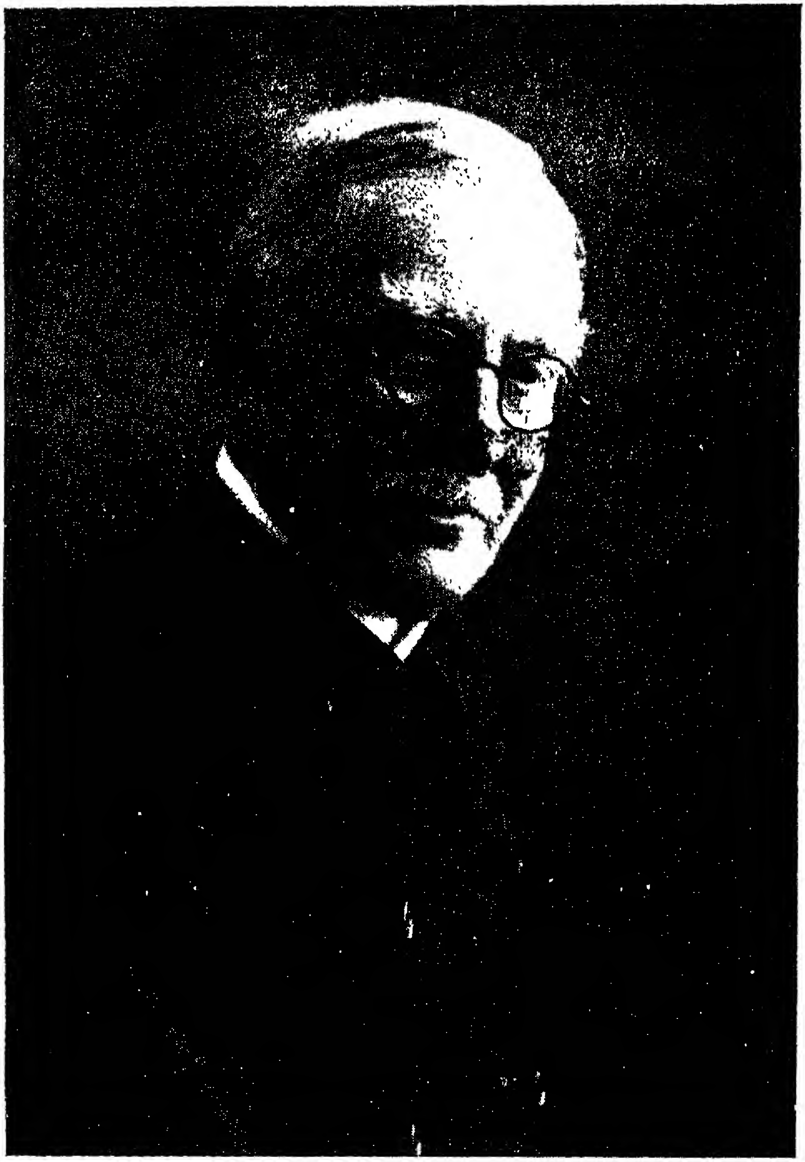


The Author, 1857–1941.

BARLEY

Fifty Years of
Observation and Experiment

BY

E. S. BEAVEN
HON. LL.D. CANTAB.

WITH A FOREWORD BY
VISCOUNT BLEDISLOE

DUCKWORTH
3 Henrietta Street London W.C. 2

FIRST PUBLISHED 1947

DEDICATED TO THE MEMORY OF

EDWARD LISLE, Esq.

LATE OF CRUX EASTON, HAMPSHIRE

whose *Observations in Husbandry* attract me as being the most delightfully written, as well as the most instructive, of all the old agricultural works. Although these 'Observations' were noted as early as 1693 (and continued until 1722, the year of the author's death), the greater part of them is still good reading for farmers to-day.

Printed in Great Britain by The Riverside Press, Edinburgh

‘John Barleycorn’s the choicest grain
That e’er was sown on land’.

From an old Folk-song.

it. But it was not until four years later, following Körnicke's publication of *Die Saatgerste*, that my interest was aroused in the evolution, classification and possible improvement of the existent races of barley. He kindly sent me a collection of ears of each of the races which he had described and the plants grown up from them formed part of the collection which I then began and have since maintained. This collection was considerably added to a few years later, when I received 300 ears, all different and botanically named, from Mr. Karl Hansen of Lyngby, Denmark.

In 1892 I was fortunate enough to meet John May Herbert Munro, and it was largely due to his initiative and stimulation that I started my experimental work on barley. He was one of a trio who for many years maintained the College of Agriculture at Downton, an offshoot of Cirencester. His colleagues were Wrightson and Fream. They had just completed a prolonged investigation on basic slag, which before that time had been a waste product and which, in consequence of their researches, has become a valuable fertilizer. Munro was also at that time in collaboration with Warington (then at Rothamsted), one of the pioneers in the study of the nitrifying organisms of the soil, which has added so greatly to our knowledge of the modes of plant nutrition.

In 1895 Munro and I made plans for investigating the manurial and other conditions affecting the malting quality of barley, and in the same year Sir J. H. Gilbert very kindly placed at our disposal all the Rothamsted barley records (many of them at the time unpublished) and gave us access to, and portions of, many of the hundreds of samples of barley preserved at Rothamsted from the crops of the previous fifty years. Our investigations of these samples led to the publication in the *Journal of the Royal Agricultural Society of England* of 'Manurial conditions affecting the malting quality of English barley' and 'Various conditions affecting the malting quality of barley'.

In 1900 I met Horace Tabberer Brown, whose writings, and in particular his classical work on barley, are well known. To him I owe much, for he was always ready to give helpful suggestions and criticisms, which were most valuable. The following year he brought Marshall Ward to Warminster to inspect my collection of barleys and Ward drew my attention

to the re-discovery of Mendel's law on the hereditary transmission of definite characters in plants. Biffen had already started on this work at Cambridge with wheat, and from that time on I paid frequent visits to Cambridge and conferred with him and T. B. Wood on the problems involved. I received constant inestimable help and advice from them, and from many others at Cambridge, and I then began what now amounts to a long series of cross-fertilizations of barley.

I could not have carried on this work (especially in latter years) without the aid of my old friend, Gosset ('Student'), whose untimely death in 1937 was regretted by so many. He kept me right with biometrical methods, which, as time went on, became indispensable for the interpretation of the mass of numerical data accumulated, and his co-operation in this respect alone has been of the greatest value.

It is quite impossible to enumerate all the kind friends who have assisted me in this adventure, but I should like to mention my eldest daughter, who, in earlier years, was of great assistance in translating the works of Körnicke and other foreign writers. My very grateful thanks are due to my two assistants, Harry Sims, my chief laboratory helper for forty-nine years, trained for me by Munro; and Harold Wickham, who for thirty-nine years past has, with his own hand, planted and harvested the collections, and who, since 1914, has supervised the conduct of all the experiments and compiled the records at the end of every season. Without the faithful and painstaking assistance of these two helpers I could not have persisted with these experiments.

. . . .

Agricultural research is a task for practical rather than for (strictly speaking) scientific men. What is really important is that the search for new knowledge and its practical application to the industry, or purpose, to which that knowledge is allied, should progress, should be welcomed, and should receive its due reward.

Edward Lisle in the Preface to his *Observations in Husbandry*, published in 1757, wrote:

'It may be looked upon, in my opinion, as one of the chief misfortunes of this age, that we have not such reasonable conceptions of a country life as might engage our gentlemen

The material of this book has been edited and put together by Miss N. Stallwood at the request of the author's family and representatives.

FOREWORD

THE inhibitions, interruptions and anxieties of the Second World War have rendered it necessary to postpone the publication of this illuminating posthumous record, by one of Britain's ablest and most successful agricultural researchers, of his scientific investigations and their remarkable results.

I am glad, at the request of Dr. Beaven's family, to furnish this brief Foreword to his book, partly because, throughout a busy public life, the application of science to the art of husbandry has been my dominant interest, partly because I valued the author's friendship and greatly admired his quite exceptional contribution to rural economic welfare and national wealth, and partly because, being by heredity and occupation a Country Squire—and proud of the fact—I always appreciated the sympathetic esteem in which he held that much-maligned section of the body politic which included in its ranks such outstanding rural reformers as Jethro Tull, 'Coke of Norfolk', 'Turnip Townshend' and Sir John Bennet Lawes.

In his Preface, Beaven accurately describes his unique achievement in cereal research as an 'adventure', aimed at providing British farmers (he might truly have said 'farmers throughout the world') with a barley which would yield a fair return for their labour by giving more quarters to the acre and a higher market value per quarter.

No cereal crop has, thanks to the author, shown more marked improvement in quality and uniformity during the last half-century than has barley, and the availability of better types has meant more nutritious food for our farm live-stock and greatly improved alcoholic beverages—beer, stout and whisky—for our human population. In this connection it is worth recalling that the late Professor Henry Armstrong, F.R.S., the eminent chemist, when decrying the mechanical extraction of the most valuable parts of the wheat grain in deference to the public craze for perfectly white bread, always emphasized the high food value of

malted beverages derived from barley as being 'the most easily circulated and most readily oxidized of all food materials'.

Beaven was as versatile as he was able and industrious. At heart a keen sportsman and lover of the English countryside, professionally a maltster, intellectually a searcher after exact knowledge, and spiritually an idealist, he conducted in his Nursery at Warminster, in Wiltshire, investigations and experiments which have revolutionized the cultivation throughout the world of its oldest cultivated cereal. His ambitious objective was its fourfold improvement: in quality, in uniformity, in stability (or strength of straw) and in climatic adaptation. All four he succeeded in securing, by breeding and selection, to an unprecedented and unparalleled degree. In addition (and this was his greatest pride) he elaborated methods of testing barleys accurately for both productivity and quality. He rightly stresses in his book the fact, and thereby exemplifies his own persistent industry, that modification, by breeding and selection, of the character of seed is more difficult and a much slower process than that of the flower, the leaf, the stem, or the root, such as constitutes the marketable value of most cultivated plants.

As his Preface indicates, some 85 per cent. of the acreage of barley now grown in Great Britain is the progeny of four plants only, three of which were selected in his Warminster Nursery in the first four years of the present century. During the past twenty-five years the crops of barley on well over five million acres of land have been the lineal descendants of the small cultures raised from single plants in this historic nursery, now, failing a male family successor of its founder, fortunately taken over and carried on by Messrs. Guinness of brewing fame.

These varieties, or 'races' as Dr. Beaven preferred to call them, have almost entirely displaced the numerous kinds, mostly mixtures belonging to many botanical races, which were generally grown in Great Britain and elsewhere forty years ago.

Not only was Beaven unique in improving, by his cultures and research, the barley crops of the world, and enhancing thereby the nutriment available to man and beast, but he was unique among modern research workers in carrying on

this beneficent and patriotic work entirely at his own expense, without any extraneous financial help. For the last 60 years most cereal crops in this country have yielded but little commercial profit to the farming community, and this would apply especially to feeding barley. But thanks to Beaven the steady improvement in the quality of malting barleys and the corresponding demands for them at good prices by the brewers and maltsters have made barley on suitable soils (and it needs a good tilth) and in capable hands a remunerative crop, even in relatively bad times. The author of this treatise exemplifies in a marked degree the fact, which we are so apt to forget, that some of our own native plants can, by breeding and selection, be made every bit as good as similar products which we have been in the habit of importing from other countries. Uniformity, he stresses, is a characteristic of at least as high a market value as outstanding quality. There was a time, not far distant, when in this country in a single field there were to be found a great variety of different plants passing under the same name in the market but of varying type and value. Thanks to the activities of Dr. Beaven in regard to barley, and to Sir Rowland Biffen, Professor John Percival, and others in regard to wheat, we can now be confident, as farmers, that we have crops of uniform quality and variety in each field sown with these cereals and can claim to receive in consequence a higher price for them when they come to be marketed.

When the scientific history of British Agriculture is written hereafter for the benefit of posterity, the name of Dr. E. S. Beaven will, assuredly, be linked with those of Sir John Bennet Lawes of Rothamsted and his partner Sir Joseph Henry Gilbert, as a great practical scientist who enriched exceedingly Britain's most vital industry and earned the undying gratitude of her whole rural community.

One grateful acknowledgement should be included and one deep regret expressed in this Foreword. The former is to Miss N. Stallwood, without whose assiduous and capable assistance this valuable record of Beaven's life's work might never have been compiled and published. The latter is to lament the loss of his gallant grandson, Lieutenant Thomas Beaven Wood, only son of the late Professor T. B. Wood, the distinguished and popular head of the School of Agriculture

at Cambridge University, whose never-failing encouragement and assistance Dr. Beaven always deeply appreciated. Beaven Wood, who had graduated at Cambridge in both science and agriculture in 1939, was killed fighting in Normandy in the summer of 1944. Had he lived, he would doubtless have endeavoured to assist in carrying on the culture and research work at Warminster, as his distinguished grandfather always hoped that he would do.

'*Ars longa, vita brevis*'

Bledisloe

LYDNEY,
GLOUCESTERSHIRE.
April 1945.

CONTENTS

PART I

OBSERVATION

PART II

EXPERIMENT

LIST OF ILLUSTRATIONS

PART I

OBSERVATION

CHAPTER I

INTRODUCTORY

It is surprising that up to the present time so little economic result has accrued from the efforts of cereal breeders as compared with those of vegetable, fruit and flower growers, or of animal breeders.

We depend on plants for our existence and shall do so ultimately in an increased measure. It therefore behoves us to utilize our energies and resources to the application of systematic methods to economic objects in the breeding and selection of the cereals.

Forty years ago we had great hopes that the work of Mendel would revolutionize our previous practice with regard to plant breeding, and perhaps animal breeding also. These hopes have not been fulfilled to any great extent. We do not now doubt that many, if not all, of the characters of organisms segregate. That was a generalization of the utmost scientific value which gave a great stimulus to experimental work. But the weak spot in its application is the fact that we have in our cultivated plants such a large number of characters to deal with. As to the number of characters in barley, the longer I go on studying this plant the greater I find the number which appear to segregate.

Vavilov [1] (1922), the indefatigable and very patient Russian observer, enumerated in a paper in the *Journal of Genetics* fifty variable characters in wheat [which he increased to sixty-six in a later work (1923)], and indicated that there are the same number, or more, in barley. He did not deal with the root system at all, and many of the characters which he enumerates vary in more than two ways and cannot be classified into pairs, so that to explain them by the doctrine of 'presence or absence' of factors becomes very complex. If he had enumerated every varying microscopic structure

[1] President of the Lenin Academy of Agricultural Sciences and Director of the Institute of Plant Industry, Leningrad, and of the Institute of Genetics of the Academy of Sciences of the U.S.S.R.

Note.—Figures in parentheses refer to Bibliography.

and had by some ingenious arrangement sorted them into pairs, he might easily have found 100 or more pairs of characters in barley, and if he had studied barley histologically he might have found 1,000 pairs. In a later paper he illustrated eighteen different forms of the arrangement of the 'denticles' on the awns of barley, and it is likely enough that similar diversity applies to other structures also. If we reckon up the total number of possible combinations of characters, taking one out of each of only a hundred pairs, we get a number which is more than one million times as many barley plants as there are on the face of the inhabited globe. As far as we know there is no reason why any of the possible forms should not exist, although it is obviously impossible that they all do. This perhaps helps us to see why we have not been able for practical and economic purposes to adhere strictly to Mendelian lines, although it must be freely admitted that the extension of Mendel's work has led to more complete understanding of the principles of heredity in cultivated plants: to much more ready combination of characters: and to more systematic methods of selecting individuals resulting from cross-fertilization from which to raise races with fixed characters.

The problem to be solved by the plant breeder is akin to that which besets the breeder of animals. Single plant cultures have to be made year after year and selections made from such cultures for the characters required.

In the Preface to the first volume of *The Golden Bough*, Sir J. G. Frazer (1913), referring to the evolution of some human characteristics, writes: 'No one can be more sensible than I am of the risk of stretching a hypothesis too far, of crowding a multitude of incongruous particulars under one narrow formula, of reducing the vast, nay, inconceivable complexity of nature and history to a delusive appearance of theoretical simplicity'.

These words seem to me to be equally applicable to the fundamental aspects of heredity.

But if we are to postulate an almost unlimited number of characters in our cereal plants, and if we admit that any of them may, and many of them certainly must, have some influence on productivity and also on the quality of the seed, and if we at the same time accept particular inheritance and

segregation, then it would seem somewhat improbable that any aggregates of cereal plants exist which can in strict correctness be called 'pure lines' in respect of productivity and quality of seed. That is a sad fact, because it is supposed that all cereal breeders without exception have based their work for a long time past upon the assumption that 'pure lines' exist, and more or less on the basis of Johannsen's work on beans self-fertilized from generation to generation (1903). But what after all did that prove? He took certain characters, such as weight of seeds, and found that such differences as arose amongst the progeny of single individuals were in that respect of a fluctuating and not of a genetic order. As far as I know he brought forward no evidence that individual plants of these aggregates did not vary genetically in some other characters. It would indeed have been difficult, if not impossible, to prove that they did not so vary. Whether or not there is a plant on the face of the inhabited globe that is homozygous in *all* its characters is probably unprovable. I think it would take all the botanists more than all their lives to prove incontestably the existence of any such plant. Perhaps the best argument for the existence of such organisms is that there are some which, as far as we can see from observation of fossil remains, have not varied materially during long geological periods. But if it is admitted, as there seems to be a tendency to admit, that organisms vary genetically in response to environment, there may also be conditions where both the environment and the organism remain constant.

I have recently become sceptical with regard to the doctrine of non-transmission of characters varying genetically in response to environment, because I have some evidence of such variation, which I believe to be conclusive, amongst my own cultures made during the last forty years. Fortunately for us, however, as breeders of plants for agricultural uses, we know that aggregates of self-fertilizing plants, which are the progeny of single individuals, are often genetically constant for long periods in respect of those characters to which we attach the greatest value.

Summing up the present position of breeding and selecting barley for value per acre to the farmer, it may be agreed that we have to start with single plant cultures and then go on

year after year selecting individuals from these cultures for the characters which we require, so that all our plants shall have a known pedigree. This is the old empirical method of Vilmorin, to which we owe not only our present sugar-beets, but also most of our best cereal races. Without the single-plant culture method the results of Mendel and his successors could not have been established, but it is to the application of this method rather than to any Mendelian theories of unit characters and segregation that we must still look for further improvement in the value of our agricultural crops.

It is a matter of great importance to this country to secure good, prolific races of barley and to ensure that the best races are grown.

In 1939 there were 6,000,000 acres of wheat, barley and oats grown in the United Kingdom, and with the exigencies of war conditions this area will of necessity be greatly increased; so that the difference between growing good, or inferior, yielding races is a matter of very considerable moment to cereal growers as a whole.

In order to maintain and increase the arable area it is necessary that each of the three cereals should be remunerative to growers in those areas to which they are best adapted. Whilst wheat is of the first importance, it is very necessary to maintain and increase the area under barley and oats.

CHAPTER II

THE ORIGIN AND ANTIQUITY OF BARLEY

AMONGST evolutionary changes throughout the ages we may be grateful to the beneficent providence which presides over the growing of our cereals for having mercifully ordained that barley, reputed of old to have been the gift of Ceres and the first plant to be cultivated, still remains barley.

There is no doubt that before there was any cultivated barley there existed wild forms of the genus *Hordeum* which were used for human food. Several of these wild forms still grow in various parts of the world. They are to be found in Palestine, Syria, the Euphrates Valley, Persia (Iran), and further east and north-east in Afghanistan and Bokhara. Many of them are not unlike some of our cultivated forms in various botanical characters and all the numerous present varieties are generally regarded as being descended from one or other of them.

If we were called upon to name the moment of time which marked the beginning of human civilization, we might safely answer that it was the moment when, for the first time, some human hand (probably that of a woman) scattered seeds with the intention of raising plants for human food. All the evidence we have makes it probable that the first seeds deliberately sown by human hands were of one of the then existing races of the wild barley to which the specific name of *Hordeum spontaneum* has been given.

Körnicke (1895) wrote:

> 'Hordeum spontaneum *is particularly interesting in the history of agriculture. It is the oldest of our cultivated plants. Its cultivation is linked up with the beginnings of settlement, and so with the further development of mankind. "That man might become man, he took an eternal pledge of faith with his mother earth". Many consider the cultivation of wheat to be of older origin. My belief in the earlier cultivation of barley is based on that of the Greeks, with whom barley played a very considerable part. The Greeks formerly inhabited Asia in districts where* Hordeum spontaneum *still grows to-day. Either their predecessors, or other nations who inhabited these districts before them,*

cultivated the plant, after having previously used the wild form as a food. "Antiquissimum in cibis hordeum", *says Pliny,*[1] *and we have it from Artemidor that the Greeks recognized barley as the oldest cultivated plant. He tells us that, according to tradition, the gods gave barley to mankind as the first form of food. It was barley that was scattered at the sacrifices of the old Greeks. These sacrifices must have taken place at a period when wheat was unknown to them. When used sacrificially, barley went by a primeval name, which all endeavours have failed to trace etymologically, namely,* Ulai. *Further, barley was the chief form of nourishment of the Greeks, and it is to be noted that at a time when the country was in its prime barley served as food in a primitive form. True, it was sometimes baked into bread, but rarely. It was generally known as* Alphita. *The barley was roasted, but only slightly, and then coarsely ground. Originally this was probably done with the purpose of making the corns mealy for easier mastication. Then the* Alphita *were stirred with water and eaten with the addition of oil and condiments. This took the place of our bread, so that* Alphita patroa *meant the paternal heritage, and just as we now say of one who has his subsistence, "He has his daily bread", the Greeks said, "He has his* alphita"'.

So we see that Körnicke, who has probably given more study to the matter from a botanical point of view than anyone else, after surveying all the evidence, is of opinion that barley is the oldest cereal, and that H. *distichum*, var. *spontaneum*, Koch, which grows wild in the East and until of late years was the only wild barley known, is the parent form (Fig. 1). He describes the plant as having long and narrow ears, and he disagrees with an earlier writer (Koch), who originally described it and who considered that it resembled H. *zeocriton*. Körnicke, however, gives as the most prominent characteristic of the wild-growing variety the fragility of the rachis.[2]

[1] *Natural History*, 18, 72.

[2] This wild grass (H. *spontaneum*), of which there are several varieties growing freely in many parts of S.W. Asia, is certainly 30,000 to 40,000 years old. The character which sharply distinguishes it from most of our cultivated races (some of which were probably cultivated 10,000 years ago) is the fragility of the ràchis; the ears fall to pieces before the grain ripens. This habit has reappeared in some recent hybrids raised by myself and others, within the past fifty or sixty years. I have no evidence that this habit was present in any cultivated races before the practice of cross-fertilization started, within living memory.

I have artificially cross-fertilized H. *spontaneum* in the nursery at Warminster with a number of races of cultivated barley and have found in every case that the progeny was fully fertile. Complete fertility of a hybrid progeny is some presumptive evidence of relationship (even if very distant) between the parents—and therefore of a common ancestry.

Fig. 1.—Wild barley (H. *distichum*, var. *spontaneum*, Koch).

To face page 8

J. G. Frazer (1912), who approached the subject of the relative antiquity of barley and wheat entirely from the standpoint of the study of mythology, was of the opinion that the culture of barley preceded that of wheat. He says:

> '*We have found independent reasons for identifying Demeter as the Corn-mother, and of the two species of corn associated with her in Greek religion, namely, barley and wheat, the barley has perhaps the better claim to be her original element; for not only would it seem to have been the staple food of the Greeks in the Homeric age, but there are grounds for believing that it is one of the oldest, if not the very oldest, cereals cultivated by the Aryan race. Certainly the use of barley in the religious ritual of the ancient Hindoos as well as of the ancient Greeks furnishes a strong argument in favour of the great antiquity of its cultivation, which is known to have been practised by the lake-dwellers of the Stone Age in Europe*'.

Quite recent discoveries in Mesopotamia seem likely to alter our scale of chronology. It appears that Mesopotamian cultivation, and therefore presumably cereal cultivation, might have been far older than any other. No such urban civilization, as the old Mesopotamian is now proved to have been, could have been possible without very large previous cereal cultures. Nomad tribes might feed on wild grain, as indeed they still do, but not inhabitants of big cities. So it looks as if we might have to put back the beginning of cereal cultivation to 20,000 or even 50,000 years, or indeed to an even earlier period. Vavilov (1926) was inclined to think on botanical and ecological grounds that barley spread outwards from two centres, one in North Africa and the other in East Asia, and he mentions Abyssinia as a possible originating centre.[1]

Origin of species will always be wrapt in mystery in the mists of millions of years ago, but our growing anthropological, archaeological, and even traditional knowledge may help us to locate with some degree of probability the period in which barley was first grown and the identity of the first human being who planted the seeds. I think it very unlikely, however, that we shall ever get beyond the speculative stage in the study of the origin of cereal cultivation.

[1] When I wrote *Varieties of Barley* (1902) I was very much struck by the wealth of forms of barley which occurs in Abyssinia. There are many more forms there still in cultivation than in any other part of the world. The '*deficiens*' forms occur only there.

I am fortunately able, with the kind consent of the Royal Anthropological Institute, to reproduce a photograph (Fig. 2) of a few grains of cultivated barley from probably the oldest store yet discovered. Stores of this grain were found by Miss Caton-Thompson and Miss Gardner (1926) in several straw-lined pits similar to that illustrated (Fig. 3), in the course of excavations by these two explorers in the Fayum, situated on the borders of the lake known in ancient times as Moeris, about sixty miles south-west of Cairo, and believed to have been placed there prior to the Egyptian 'Sequences'. These excavations disclosed the remains of the culture of a Neolithic race of men who lived there and cultivated barley at a time which has been variously estimated at 5,000 to 10,000 years ago. How long before the time of these people barley was in cultivation we are never likely to know.

Miss Caton-Thompson and Miss Gardner appear to think that the race of men who inhabited this area arrived there some centuries earlier than 5,000 B.C. Professor Sir Flinders Petrie had originally put the date far earlier and had suggested some such date as 15,000 B.C., basing his estimate mainly, as far as I understand, on geological evidence.

Samples of the Fayum Neolithic grain were examined by several experts, viz., the late Dr. Otto Stapf, Dr. John Percival, Sir Rowland Biffen; and by Mr. A. Jackson (of Messrs. Guinness, Dublin), who examined the specimens of barley only. There was a quite definite discrepancy in respect of the identification of the barley grains as being either of the sub-species H. *hexastichum* or H. *vulgare*; or a mixture of both.[1]

Details of the determinations made on the grain are related in Miss Caton-Thompson's and Miss Gardner's more recent work, The Desert Fayum (1934).

It is difficult to distinguish with certainty between grains of H. *hexastichum* and H. *vulgare*, especially if the material

[1] Barley and Emmer (probably the original wheat plant and one of the most ancient cultivated cereals) might have been often grown as mixtures and perhaps from the very outset of civilization. H. *spontaneum* and T. *dicocciedes* (Wild Emmer) are still found growing together in Palestine and, as far as I know, Emmer has always been found mixed with the prehistoric samples. Also mixtures of barley and wheat are referred to in the earliest records we have and the custom of sowing mixtures of these two cereals still survives. Emmer was the only wheat grown in Egypt for many thousands of years.

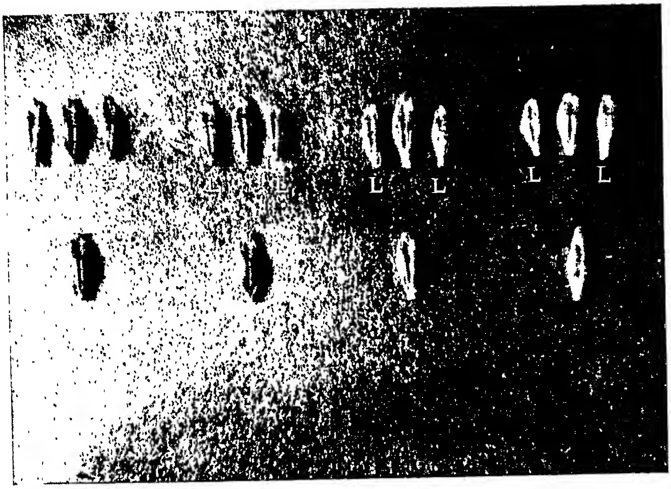


FIG. 2.—Grains of Neolithic barley.
L.: Lateral grains.

FIG. 3.—Straw-lined pit granary.

To face page 10

is 5,000 to 10,000 years old, unless one has the rachis, or portions of it. Fortunately, in this case, there were portions. The fact that the internodes were over 3 mm. apart, however, made it evident that the barley belonged to the sub-species H. *vulgare*. The shape of the corns also confirmed this opinion. The sample contained a mixture of about 25 per cent. wheat.

Mr. A. Jackson, who examined the material from three pits very thoroughly, in a contribution to Nature (1933), *described the barley as consisting of two varieties, six-rowed and two-rowed.*

In the illustration shown (Fig. 2) those grains marked L, which are slightly twisted, are probably the lateral ones of a six-rowed variety; the others may be either median grains of a similar variety, or grains of a two-rowed variety.

From an Early Iron Age settlement at Fifield Bavant Down, Wilts, grains of barley (as well as wheat and oats) were discovered about thirty years ago.[1] I obtained and examined a sample of this barley drawn from the bulk and found that, like the Fayum grain, it was a mixture of Emmer and Barley. This grain was probably grown 2,000 to 3,000 years later than the Fayum specimens, but it is quite conceivable that it took an equally long period to reach here, either from Egypt, or from further east. We know little as to the age when cultivation began in England, but it probably originated on our Chalk uplands.

The fact that Emmer and Barley mixtures are found in locations so far apart is consistent with a belief that the first grain to be cultivated was a mixture of these two. It is also significant that H. *spontaneum* and Wild Emmer are often found growing together.

Some of the oldest specimens of cultivated barley which I believe are in existence in this country are preserved in the British Museum:

1. In the Egyptian Department there is a jar of grain from Thebes believed to date from between 1,200 and 1,500 B.C. It is remarkably well preserved and without

[1] Specimens of the Fifield Bavant barley are to be found in the Devizes Museum, Wilts. This grain has been referred to as *hexastichum*, but judging from the photograph of the rachis (see *Wilts Archaeological Magazine*, June 1924, Plate XVII, Fig. 1) I should be inclined to designate it as *vulgare*.

doubt is six-rowed barley, not dissimilar to H. *vulgare* as now grown. The shape and size of the grain are those of a rather small Yerli (Smyrna) barley; some of the grains of the lateral florets, however, are very small. The rachilla is of the same type as that common to H. *vulgare* as now grown, viz., nearly smooth with a few bristles at the apex.

2. In the Ethnological Department there is a collection of carbonized grain from the Swiss lake dwellings: the date may be anything between 2,000 and 3,000 B.C.

There is no doubt that this latter is H. *hexastichum*. No wild barley with short internodes like H. *hexastichum* is known, but it is conceivable that such a plant, now lost, may have been the parent form of the sub-species *hexastichum* (six-rowed) and *zeocriton* (two-rowed).

Barley is very frequently portrayed on ancient coins, and from an examination by Munro and myself of a collection of casts of all the coins in the British Museum bearing representations of barley (kindly sent to us by Mr. G. T. Hill, of the Coin Department, some forty years ago) it seems that the older Western barleys were of this type, viz., with wide spikes and short internodes. This appears to afford some additional evidence in favour of more than one parent form.

Of these casts, those which show the most detail, and at the same time the most beautiful and careful design, are from Metapontum, in South Italy, and date from between 600 and 300 B.C. They evidently portray wide-eared, six-rowed barley, and on photographing the coins and ears of H. *hexastichum* side by side there appears a close resemblance in the shape of the ears, and in the angle between the grain and the rachis. Fig. 4A represents the oldest of the Metapontum coins. There is also one British coin of Cunobelin, struck at Camelodunum (Colchester) about the beginning of the first century B.C., the obverse of which is occupied by an ear of barley. The design is much less careful than that of the Metapontum coins and is somewhat diagrammatic; but Munro and I came to the conclusion that it also represents wide-eared barley, though in this case that of the two-rowed variety (Fig. 5A). We received from Dr. Hans Schinz, of the University of Zurich, a paper written by the late Professor

FIG. 4A.

FIG. 4B.

FIG. 5A.

FIG. 5B.

FIGS. 4A and 5A.—Ancient coins depicting ears of barley.
FIGS. 4B and 5B.—Wide-eared six- and two-rowed barleys.

To face page 12

Oswald Heer, which contained a number of most carefully executed figures of ears and grains of barley found by him when excavating the lake dwellings of Robenhausen. They were previously referred to by the writer of the article in the *Ency. Brit.*, and also by Mr. H. Stopes (1895). They are unmistakably wide-eared barleys. We further received from Dr. Messikommer, of Wetsikon, Canton Zurich, a colleague of the late Professor Heer, a number of actual grains of barley found in the lake dwellings. They are all carbonized. Under what conditions this happened appears doubtful, but the ancients were apparently accustomed to roast barley for use as food. The grain is short and plump in shape, and at first sight looks like 'naked' barley, but Dr. Schröter, of the Museum of Zurich, where Dr. Heer's original specimens of ears are preserved, informs us that he is of opinion that this is not the case. Professor Heer suggests that if the existing sub-species have a common origin, then the H. *hexastichum* of the lake dwellings is the probable ancestor of the other types, for it is more likely that improved cultivation has resulted in the lengthening of the ear than the reverse. He mentioned the finding of one ear of two-rowed barley, which, however, was unfortunately lost, and which he considered to have been rare in this age. It seems probable that the infertile florets of two-rowed barley were originally fertile, and some of the older agricultural writers say that two-rowed barley will degenerate into six-rowed grain under adverse conditions.[1] On this point we have no direct evidence available.

[1] *General Report on Agriculture, etc., of Scotland,* Sir John Sinclair, Bart., President of Board of Agriculture, etc., 1814, vol. i, p. 495.

CHAPTER III

VARIETIES OF BARLEY

Classification and Nomenclature

It can hardly be said that there is at present in this country any generally adopted scheme of classification of barley, or of the cereals in general; or indeed that there has been any systematic study of the varieties of barley and of the morphological differences which they represent.

The earliest classification of the genus *Hordeum* of any moment was that of Linnaeus, in 1748, followed five years later (1753) by a more elaborate version. Körnicke (1882) published a monograph on barley, which contained a classification of all the forty-four varieties then known, with a very beautiful set of illustrations. This was followed by the *Handbuch des Getreidebaues* of Körnicke and Werner (1885). The first volume gives a description of all the varieties of barley then known, as well as of the other cereals; the second volume relates the results obtained by cultivating almost every kind of grain (including all our well-known sorts of English barley) on the plots attached to the Landwirtschäftlichen Akademie at Poppelsdorf, near Bonn. There is nothing in the English language comparable to this encyclopaedic work on the whole of the cereals, but Percival (1921) has filled the gap for wheat with his magnificent monograph on that cereal.

The study of the varieties of barley, in addition to having been continued at Poppelsdorf by Körnicke, has been actively carried on by Rimpau (1891). Amongst others who have made contributions to the classification of barley are Atterberg (1899), whose very complete system has been fully described by Dr. Hunter (1926); Dr. Harlan (1918) of the U.S. Department of Agriculture; and R. G. Wiggans (1921) of the Cornell University Agricultural Experiment Station.

No two botanists have ever adopted the same classification. The fact is that schemes of classification are necessary, but fail theoretically. This arises from the fact that definitions

of the various 'groups', e.g. genus, species, variety, etc., are all arbitrary. It would be otherwise if any one group received general acceptance.

Now that racial affinities are better understood than in the age of Linnaeus it seems that the term 'species' at least might receive some authoritative definition, at any rate for the higher orders of plants and animals, and I suggest that a definition which would lead to the least disturbance of existing nomenclature might be: 'A group of plants (or animals) the individuals of which can interbreed freely and whose progeny are similarly fertile'.

No doubt all sorts of objections could, and would, be raised, but such a definition would embrace all the cultivated barleys and also the wild species *Hordeum spontaneum*, so that they would all fall into one species. They were, in fact, so classified by Linnaeus (1753), and in our time by Körnicke (1882).

When we come to the groups into which 'species' may be divided the confusion becomes very great. It is as complicated with barley as it is with the human race.

Percival (1921), dealing with wheat, divides the genus *Triticum* first of all into two species of wild plants and then into eleven races of cultivated forms. He subdivides 'races' into 'varieties' and bases the latter on the following hereditary characters:

1. Presence or absence of awns.
2. Colour of glumes (white, red or black).
3. Colour of awns (white, red or blue).
4. Glabrous or pubescent glumes.
5. Colour of grain.

He splits 'varieties' up into 'forms' and defines the latter as 'the progeny of a single individual, the origin of which may, or may not, be known for certain', and gives as examples Purple Straw, Red Fife, Squarehead, and other wheats.

Some writers use the term 'race' to designate any aggregate of plants which possess the same inherited characters, and, since there is a presumption that such aggregates have a common ancestry, this seems to be a more descriptive term than 'form'.

It is fairly obvious, first, that we cannot get a satisfactory

definition to distinguish varieties and forms; and, secondly, that we cannot continue to attach Latin names even to every new variety, still less to every new form.

Take, as an example, the two, so-called, forms, *Hordeum distichum*, var. *nutans*, form Chevalier, and *Hordeum distichum* (or *zeocrithum*), var. *erectum*, form Goldthorpe. Now there are scores of distinguishable forms of var. *nutans*, many of which are known to be races in the sense that the aggregates are descendants of a single plant. The same applies to var. *erectum*.

There are at present multitudes of hybrid forms resulting from crosses between forms of *nutans* and *erectum*, many of which are intermediate between the two in respect of length of the rachis and width of ear, which are the distinguishable characters of *nutans* and *erectum*.

I am, with much hesitation, inserting in Appendix A to this volume a list of hybrid varieties of barley. I believe that in 1902 *this list was a complete one and I had myself grown plants of each of the varieties named. But at that time I did not foresee that I should have grown, for over forty years, thousands of different forms of barley, of which more than three-fourths were the progeny of a single plant, and of which many hundreds might almost certainly have given rise to constant races if they had been multiplied. It will be seen therefore how impossible it is to attach botanical names to every new form of cultivated plant, whether it is a 'pure race' or not.*

The term 'variety' in a botanical sense is used to distinguish plants belonging to the same species, but differing in some structural respect which persists through succeeding generations. Varieties are supposed to have had within some measurable time a common ancestry, and, furthermore, the individuals by natural or cross-fertilization with others of the same species will give rise to new varieties, generally of an intermediate character, but occasionally differing widely from either parent.[1]

[1] The term 'variety' is frequently used in a much looser sense for aggregates, such as, for instance, Californian, Indian or Algerian barleys, which differ from one another mainly (or sometimes entirely) through the effects of climatic conditions; or, alternatively, for such aggregates as 'Scotch Common', which by the process of natural selection have acquired some definite characters, such as early ripening, although they may be composed of many different races. I prefer the term 'type' for all these aggregates and to use the term 'variety', in its true botanical sense, to distinguish aggregates having quite distinct morphological characters, such as *Hordeum distichum*, var. *nutans* = Chevalier, etc., *Hordeum zeocriton*, var. *erectum* = Goldthorpe, etc.

Botanical Classification

The botanical classification of barley, as in most of the plants of the higher orders, depends on the form of the inflorescence and its members, so that in the genus *Hordeum* we may confine our attention to the form of the spike or ear, to that of the floral appendages, and, what is of still more interest, to the caryopsis or fruit.

(a) *Linnaean Species*[1]

There is a tendency amongst modern authorities to consider all our cultivated barleys as belonging to one species. Linnaeus and the earlier botanists had recognized six species:

Hordeum hexastichum *Hordeum vulgare*	Six-rowed barleys.
Hordeum distichum *Hordeum zeocriton*	Two-rowed barleys.
Hordeum coeleste *Hordeum nudum*	Naked barleys.

Later botanists (e.g. Atterberg) have usually ranked all these as sub-species or groups, or races of one species, and have adopted for the species as a whole the botanical name of H. *sativum*.

The implication is that all the varieties have had a common origin. There is no direct evidence that this is so. Körnicke, in one of his many works in which he refers to wild barleys, says: 'In 1916, we found in Persia and Transcaspic Province and in Bokhara a number of spring varieties of wild barley with typical bristle spikelets, varieties with black ears, with smooth as well as with hairy glumes'.

(b) *Varying Structures*

The straw or stem of barley, as in all cereals, is hollow, except at the nodes or solid joints, from which the foliage leaves of the plant arise; the lengths of stem between the nodes are the internodes.

The wild *Hordeum spontaneum* has relatively to the

[1] Linnaeus, *Sp. Pl.*, 84.

cultivated races a long, thin stem; the actual length may be anything from less than 2 ft. to over 4 ft., according to the environment. In all barleys the uppermost internode immediately below the ear is always the longest, though there is considerable genetic and fluctuating variability in its length in the different races.

The primary axis of the spike or ear of barley, called the rachis, is divided, like the straw or stem below, into internodes which are very short and of which there may be any number up to forty.

The length of the internodes in H. *spontaneum* measure from 6·0 to 9·5 mm. (average 7·2) and are longer than those of any cultivated races. In the latter the length of the internodes is approximately 2·8 to 3·6 mm. in the long, narrow-eared races of both two-rowed and six-rowed barleys, and from 2·1 to 2·6 mm. in the short, wide-eared races. Intermediate lengths are met with amongst artificially produced hybrids and there is also considerable variability.

At the base of each internode of the ear is a node or notch, from which three single-flowered spikelets arise, the threes being arranged alternately on either side of the rachis. These three spikelets are each apparently sessile upon the rachis, that is, attached directly to the main axis. There is present a rudimentary secondary axis or rachilla to each spikelet which does not function as such and which differs in structure in different varieties. Percival (1936) suggests that the three spikelets of cultivated barleys may be looked upon as springing from 'a primary branch, with two opposite lateral branches each bearing one flower', but the branch, if it existed in the parent form, has become merged in the rachis, and only the three secondary branches remain, and these only as rudiments.

Of the three spikelets springing from each notch of the rachis either all three (namely, the median and the two lateral), or only one (the median) may be fertile. In the former case the barley is said to be six-rowed (Figs. 6 and 7), and in the latter case two-rowed (Figs. 8 to 11), the superimposed spikelets in each case forming vertical rows.

It has sometimes been stated that there is a third form, viz., the median row infertile (staminate or male) and the two lateral fertile (bisexual), thus giving a four-rowed barley.

This occurs in one of the wild barley grasses, H. *sylvaticum*, but not in any cultivated variety, or if it does occur it is a mere 'sport', and not constant.

The flowers of the lateral spikelets of the commonly cultivated two-rowed barleys are staminate only, with rudimentary ovaries.

This distinction between six-rowed and two-rowed varieties gives us the first broad grouping into which the genus is divided.

Between the six- and two-rowed groups there is an intermediate form, the H. *intermedium* of Körnicke. The lateral spikelets of this group although fertile are small and devoid of awns, and Körnicke considers the two varieties (one wide-eared and one narrow-eared) which present this condition to be entitled to rank as a separate group or sub-species.

For the purpose of a more extended classification we have to take into account (1) the shape of the spike or ear, (2) the variation in the forms of the spikelets.

The ear, both in the six- and two-rowed sorts, may be wide and short, or narrow and long, and the arrangement of the spikelets differs in the wide- and narrow-eared forms; also the ears of the wide-eared sub-species are more erect after ripening, and those of the narrow-eared ones more inclined to droop.

Passing from the form of the ear to that of the spikelet and its enclosed caryopsis, the latter is enclosed by the outer and inner paleae, commonly called the husk, the outer palea usually terminating in an awn. The paleae and their appendages, the awns, differ in respect of adherence or non-adherence to the pericarp of the caryopsis, also in colour and shape, and so give rise to many varieties.

The foliage system considered morphologically includes the paleae and awns. Diverse forms of these are racially characteristic. In H. spontaneum *and the common cultivated sorts the paleae terminate in long serrated awns. The degree of serration of the awns is a genetic factor. In some races awns are replaced by a structure which in some respects has no parallel in any other species. In the case of H.* trifurcatum, *which is in common cultivation in some Himalayan districts, in place of an awn the outer palea terminates in a 'trifurcate' appendage, which contains a rudimentary floret. In some hybrids this floret is complete, and*

Biffen some years ago collected ripe seeds from one single floret reproducing the characters of the parent plant. Awns are transpiring organs and it seems probable that the replacement of them by this structure renders the plant more xerophilous. In some hybrids obtained by crossing H. trifurcatum *with awned forms, the awn is entirely absent and the outer palea terminates in an acuminate point.*[1] *In some cultivated races the awns are very brittle at their lower extremity and fall off readily from the paleae before, or after, the time of ripening of the seeds.*

In H. spontaneum, *and in most of the cultivated races, the paleae adhere closely to the pericarp of the caryopsis and form part of it for all practical purposes. There is considerable variation in the colour of the paleae of different natural varieties after ripening: this ranges from deep black to pale yellow. The races more generally cultivated in Europe have yellowish ripe paleae but there are distinct genetic degrees of this colour. The colour of the ripe pericarp is also genetically variable from pale yellow in H.* spontaneum *and most cultivated races to black in some species of Asiatic and Abyssinian origin, and is not always associated with similar colour of the paleae. The aleuron cells of the endosperm also frequently contain pigment of different shades of bluish-green, and this is also a genetic character of barley which has received little attention.*

The other accompanying structures are the glumes outside the paleae and at the base of the grain. They correspond to the outer glumes of wheat, but are very much smaller and, like the paleae, they differ in form and give rise to varieties. The abnormal forms may be considered to be retrograde and they have no agricultural value.

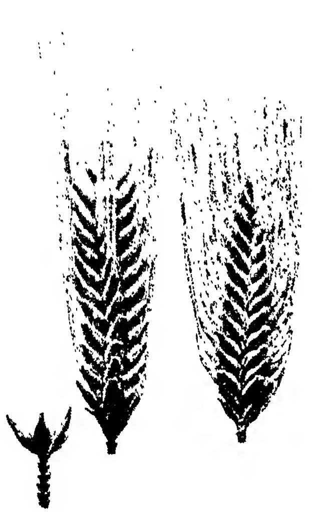
The rudimentary rachilla varies in form, and more particularly in respect to the extent to which it bears hairs.

There seems to be no well-established theory as to the structural significance of the rachilla and some doubt as to whether it is the remnant of a 'branch' of the rachis, as Wiggans (1921) indicates.[2]

It has been suggested that the outer palea (Wiggans' 'Lemma') might be regarded as a modified branch of the rachis rather than as a modified leaf, the reason for this being

[1] Two-rowed awnless barley is one of many forms obtained by Rimpau by crossing var. *Steudelii* (black Abyssinian barley) with var. *trifurcatum*, naked Nepal barley.

[2] As far as I know the type of rachilla is quite constant in the progeny of single self-fertilized plants, i.e. it is a genetic and not an environmental character, but of course one gets both smooth and rough and intermediate types of rachilla in hybrids, and also in most commercial bulks.



a *b* *c*

H. HEXASTICHUM.

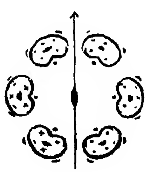


Fig. 6.

a. Three spikelets *in situ* on the rachis, showing short internodes.
b. Spike. Median spikelets uppermost, and with lower awns removed.
c. Spike. Lateral spikelets uppermost, and with lower awns removed.

a *b* *c*

H. VULGARE.

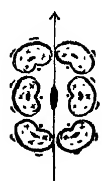


Fig. 7.

a. Three spikelets *in situ* on the rachis, showing long internodes.
b. Spike. Median spikelets uppermost.
c. Spike. Lateral spikelets uppermost.

The diagrams show the relative position of the spikelets to the rachis when projected on a flat surface, the spike being in position *c*.

The arrow passes through the longer transverse axis of the rachis. The three spikelets on each side spring from the same internode. A dot opposite the furrow of the inner palea indicates the rachilla. The ovary occupies, in the flowering stage, the centre of the spikelet, and is surrounded by three stamens × and two lodicules –. The position of the glumes is indicated outside the outer palea –.

To face page 20

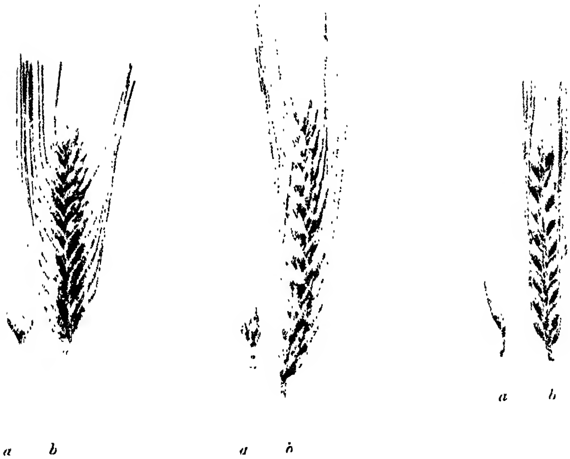
Fig. 8.

Fig. 9.

a, d. Spikelets. Rachis edgewise, showing short internodes.
b. Var. *zeocrithum* (fan barley). Spike converging.
c. Var. *erectum* (Goldthorpe). Spike parallel.

a, d. Spikelets. Rachis edgewise, showing long internodes.
b. Var. *nutans* (Chevallier).
c. Ouchak barley.

The diagrams show the spikelets projected on a flat surface. See Figs. 6, 7.



H. INTERMEDIUM
VAR. TRANSIENS. VAR. HAXTONI

H. DECIPIENS.

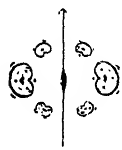


FIG. 10*a*.

H. *intermedium*, Kcke.
var. *transiens*
(wide form).

a. Three spikelets *in situ*, median spikelet uppermost.
b. Spike. Lateral small awnless spikelets uppermost.

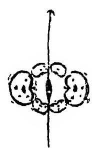


FIG. 10*b*.

H. *intermedium*, Kcke.
var. *Haxtoni*.
(narrow form).

a, *b* as Fig. 10*a*.

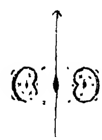
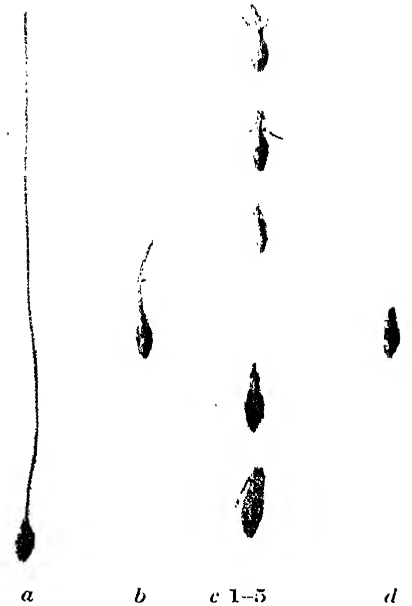


FIG. 11.

H. *decipiens*, Steudel.

a, *b* as Fig. 10*a*, 10*b*.

The diagrams show spikelets projected on flat surface. See Figs. 6, 7.



a. Normal form.
b. Short awn terminating in trifid appendage.
c. 1–3. Trifurcate paleae.
c. 4–5. Trifurcate paleae, naked grain.
d. Awnless palea.

FIG. 12.— Variation in the paleae of *Hordeum*.

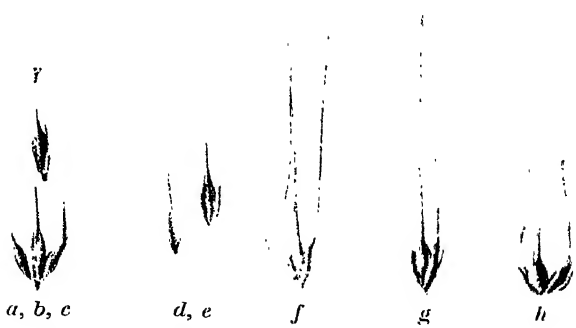


FIG. 13.—Variation in the glumes of *Hordeum*.

a. Segment of rachis. Glumes *in situ*. Grain removed. Normal form.
b. Spikelet of H. *distichum*. Glumes and grain *in situ*. Normal form.
c. Spikelets of H. *vulgare*. Glumes and grain *in situ*. Normal form.
d. Ovate-lanceolate glume of var. *recens*.
e. Spikelet of H. *distichum*, var. *Kornickei*. Glumes lanceolate.
f. Spikelet of H. *distichum*, var. *Braunei*. Glumes of median spikelets lanceolate and awned.
g. Spikelet of H. *distichum*, var. *Rehmii*. Glumes of all the spikelets awned.
h. Spikelet of H. *hexastichum*, var. *eurylepis*. Glumes of all the spikelets ovate-lanceolate and awned.

that it sometimes bore (as in the hooded races) florets, and there is no known case in the Angiosperms, as I understand, of flowers being carried on leaves, although they are sometimes carried on leaf-like branches, as in 'Butcher's Broom'.

The several structural forms above referred to are illustrated by Figs. 6 to 15.

(c) *Classification* [1]

Hordeum sativum, Pers. [2] (H. *vulgare*, Kcke.)

SUB-SPECIES OR RACES

1. Spike of six rows of spikelets, all fertile.
   - A. Wide, with short internodes, H. *hexastichum*, L., Fig. 6.
   - B. Narrow, with long internodes, H. *vulgare*, L. [3] (H. *tetrastichum*, Kcke.), Fig. 7. (Both common.)

2. Spike of six rows of spikelets, all fertile—two median rows normal, four lateral rows diminutive and without awns.
   - A. Wide, with short internodes, H. *intermedium*, Kcke. (var. *transiens*), Fig. 10, *a*.
   - B. Narrow, with long internodes, H. *intermedium*, Kcke. (var. *Haxtoni*), Fig. 10, *b*. (Both rare.)

3. Spike with two median rows of spikelets fertile and four lateral rows infertile or staminate.
   - A. Wide, with short internodes, H. *zeocriton*, L., Fig. 8.
   - B. Narrow, with long internodes, H. *distichum*, L., Fig. 9. (Both common.)

4. Spike with two median rows of spikelets fertile, and four lateral rows rudimentary and without floral organs.
   - H. *decipiens*, Steudel (several Abyssinian varieties), Fig. 11.

If each of the forms were represented by wide and narrow forms we should have eight groups or sub-species. No. 4 is only narrow-eared in natural varieties, but there is a hybrid wide-eared form.

[1] This classification follows that of Körnicke, with only a few unimportant amendments of which he approved.
[2] Persoon, *Synopsis*, I, 108.
[3] Linnaeus, *Sp. Pl.*, 84.

VARIETIES

Within the several sub-species we have varieties cultivated in various countries differing in the character of the spikelets and their appendages in the following respects:

1. The adherence or non-adherence of the paleae to the pericarp.
   - (*a*) The common form with adherent paleae.
   - (*b*) Naked barleys.

2. Colour of (1) the paleae, (2) the caryopsis. [The colour of the caryopsis may be due to colouring matter in the pericarp, or in the aleuron cells as pointed out by A. J. Brown (1900). There are, furthermore, some black barleys which have colouring matter in the starch-containing cells of the endosperm whilst they are in a steely condition, but as the process we know as mellowing proceeds the colour disappears.]
   - (*a*) Yellow or white paleae and caryopsis.
   - (*b*) Yellow or white paleae with bluish-grey caryopsis.
   - (*c*) Brown paleae.
   - (*d*) Black paleae. The colour of the caryopsis when naked in the two latter cases also varies.

3. Variation of form of the outer paleae.
   - (*a*) Normal form with serrated awns, Fig. 12, *a*.
   - (*b*) With smooth awns.
   - (*c*) Awns replaced by or terminating in three processes, Fig. 12, *b*, c^1–c^5, one of which is generally recurved, and frequently bears a rudimentary flower (c^1, c^2). The palea is then said to be trifurcate.
   - (*d*) Without awns, i.e. the paleae terminating in a mere point (acuminate), Fig. 12, *d*.

4. Variation in the glumes.
   - (*a*) The normal form of two narrow spear-shaped glumes, Fig. 13, *a*, *b*, *c*.
   - (*b*) The normal glumes of the median spikelets in the six-rowed sub-species replaced by ovate-lanceolate or boat-shaped bracts, sometimes bearing awns, Fig. 13, *d*, *e*, *f*.
   - (*c*) The glumes of the lateral spikelets so replaced, Fig. 13, *g*.

FIG. 14.—Smooth rachilla of Chevallier barley H. *distichum, in situ on the rachis.*

FIG. 15.—Bristly rachilla of Goldthorpe barley H. *zeocriton, in situ on the grain.*

NOTE.—When the grain is not very fully ripened the rachilla sometimes adheres to the rachis, as in Fig. 14. Generally, with both kinds, it is attached to the grain as in Fig. 15.

To face page 22

(*d*) The glumes of all the spikelets so replaced, Fig. 13, *h*.

5. Variation in the rachilla.

(*a*) The rachilla long, with very short, woolly hairs (villous), or nearly hairless (glabrous), Fig. 14.

(*b*) The rachilla short, and bearing long, stiffer hairs (hispid), Fig. 15.

If we imagined every combination of the above forms to occur we should have several thousands of varieties; but fortunately this is not the case, and we can reduce the natural varieties to the list given in Appendix A, all of which are described by Körnicke. Of each of these varieties I possess specimen ears, together with others which have been obtained by cross-fertilization. The number of these is likely to increase indefinitely.

The above classification and nomenclature differ from that of Körnicke in three particulars:

(1) In the common form of six-rowed English barley or Scotch bere (H. *vulgare*), the two lateral rows of spikelets springing from one side of the rachis either partially or entirely intersect, and overlap the alternate lateral spikelets which spring from the opposite side of the rachis.[1] This has given rise to the use of the term 'four-rowed barley', and the term may be admitted as a common name; but the corresponding botanical term, H. *tetrastichum,* has, I think rather unfortunately, been applied to this sub-species by Körnicke. He transfers the term H. *vulgare* to include all the cultivated barleys (and also H. *spontaneum,* which he supposed the parent form), but English botanists always use the term H. *sativum* as the specific name for all the cultivated barleys, and it seems desirable therefore to continue to restrict H. *vulgare* to the so-called four-rowed barley or 'bere', to which Körnicke gives the new term *tetrastichum.* There is, strictly speaking, no cultivated 'four-rowed' barley, as this name would seem to suggest.

(2) Körnicke includes all two-rowed barleys in the sub-

[1] Very rarely the corresponding *median* spikelet is infertile, so that the spike appears to be 'two-rowed' towards the apex.

species H. *distichum*. It appears, however, that there is just as much reason for ranking the wide short-eared varieties of two-rowed barleys (considered by Linnaeus to be a species) as a sub-species distinct from the long, narrow-eared, two-rowed varieties, as there is for the closely analogous differentiation of the short- and long-eared sub-species *hexastichum* and *vulgare*. This brings the Goldthorpe barleys into the sub-species H. *zeocriton*. They are not as short and wide in the ear as the older form so named; but classification of cultivated species is largely a matter of convenience, and it appears to me that the above arrangement is logical and convenient, and therefore justifiable.

(3) Lastly, at the other end of the scale we have several Abyssinian varieties of two-rowed barley which have hitherto been ignored by English writers, the lateral spikelets of which are quite rudimentary, i.e., reduced to a mere bract, and develop no floral organs. These appear to me to be even more entitled than the intermediate form before mentioned to rank as a sub-species and, as they are undoubtedly constant in form, I propose to group them under the name of H. *decipiens*, the name given to them by Steudel, who was one of the first European writers to describe them.[1]

Typical examples of each of the four principal groups or sub-species of barley are represented in the United Kingdom and in imported grain:

Hordeum hexastichum (commonly known as 'six-rowed barley') is of the same sub-species as our own winter barley, but there are many varieties and the growth of no two countries is alike. It is grown in England only as a winter sort, and mainly as a forage plant. It is known in France as 'Escourgeon'. Sometimes imported from Syria; also found in 'brewing Chilian'. It has a very limited range compared with H. *vulgare*.

Hordeum vulgare, known as 'four-rowed' or 'bere'. There are winter and spring sorts in the United Kingdom. Most of

[1] *Syn. Gram.*, p. 351.

the Smyrna and foreign 'brewing' barleys also belong to this sub-species.

Hordeum zeocriton is now known in Great Britain as Goldthorpe or Spratt barley. The earlier and still wider-eared, but more tapering form, known as 'fan' or 'peacock' barley, has gone out of general cultivation.

Hordeum distichum is the sub-species to which the Chevalier and all the other narrow-eared two-rowed sorts belong. Ouchak and many long, thin-grained Eastern barleys are also in this sub-species.[1]

The other sub-species or races are:

Hordeum intermedium (not cultivated anywhere on an agricultural scale), and

Hordeum decipiens, cultivated at present, I believe, only in Abyssinia.

Needless to say a large number of the varieties with abnormal forms of spikes are not in general cultivation anywhere and the majority of them have no agricultural value.

(d) *Varieties of Imported Barleys*

The following list refers barleys of foreign growth, which are in common use in this country, to their several botanical sub-species and varieties. Except where a note is appended giving the source of information, the variety to which the barley is referred has been determined by cultivating the grain of the several descriptions on small plots at Warminster.

Chevalier Californian	H. *distichum*, with some admixture of H. *vulgare*, vars. *pallidum* and *coerulescens*.
Brewing Californian	H. *vulgare*, vars. *pallidum* and *coerulescens*.
Chevalier Chilian .	H. *distichum*, with some admixture of H. *vulgare*.

[1] The relative length, size and shape of the grain, apart from any other feature, does not constitute 'variation' in a botanical sense. Like colour within certain limits, this feature is constant only so long as climatic and other conditions are unchanged. It is quite conceivable, as I have indeed been told is the fact, that Ouchak barleys were originally seeded from a Chevalier sort. It is certain that when grown for a few generations in a colder climate the grain becomes much shorter and plumper.

Brewing Chilian .	H. *hexastichum*, var. *parallelum*,[1] and H. *vulgare*, vars. *pallidum* and *coerulescens*.
Mexican . .	H. *vulgare*, vars. *pallidum* and *coerulescens*.
Argentine . .	H. *vulgare*.
Morocco, Algeria, and Tunis.	H. *vulgare*, vars. *pallidum* and *coerulescens*.
Tripoli (Ouchak type).	H. *distichum*.
Gaza . . .	H. *vulgare*.
Persian . . .	H. *hexastichum*, var. *pyramidatum*; H. *vulgare*, vars. *pallidum*, *nigrum*; H. *distichum*, vars. *nutans*, *medicum*, *persicum*, *nigricans*.
Beyrout . .	H. *hexastichum*, var. *pyramidatum*; H. *vulgare*, vars. *pallidum* and *nigrum*; H. *distichum*, vars. *nutans*, *nigricans*.
Smyrna (Yerli) .	Mostly H. *vulgare*, var. *pallidum*, but frequently mixed with H. *distichum*.
Ouchak . . .	Mostly H. *distichum* (long-grained) but mixed with H. *vulgare*.
Marmora . .	H. *vulgare*, var. *pallidum*.
Black Sea (Azof, Ghenigesk, Bessarabian, Theodosian, Tulcia)	H. *vulgare*, var. *pallidum*, generally with some admixture of H. *distichum*, var. *nutans*.
Danubian . .	Both H. *vulgare* and H. *distichum*, and often mixed.
Cyprus . . .	H. *vulgare*, var. *pallidum*.
Spanish . .	H. *vulgare*, vars. *pallidum* and *coerulescens*.

Mixtures of two-rowed and six-rowed barleys are, as will be seen, common in most foreign barleys. The relative proportion of each can be approximately ascertained by separating from a sufficient number of grains those in which the furrow is straight from those in which it is curved. The

[1] From Professor Adrian J. Brown, School of Birmingham, Birmingham University.

grains of the lateral rows in six-rowed barley have more or less curved furrows, and if the barley is all six-rowed there will be twice as many of these as of grains with straight furrows. The character of the rachilla cannot be relied on to make the separation, because although *vulgare* has generally a rachilla without hairs, and *distichum* of the Ouchak sorts generally have some hairs, this difference is not at all constant.

Mixtures of wide - and narrow-eared barley are becoming frequent in native-grown barley. Goldthorpes can generally be recognized by a bristly rachilla. True Chevaliers have a nearly smooth one, but there are specimens of wide-eared barley with a smooth rachilla; and many narrow-eared sorts have a more or less bristly rachilla. The paleae of the wide-eared barleys are less closely adherent, and the colour is almost always paler. The grain is larger than that of Chevaliers. Threshing machines and drills are frequently answerable for intermixture which ought to be avoided, especially for seed-corn.

CHAPTER IV

THE BARLEY SEED

Germination, Growth and Migration

The natural function of a seed of barley within each grain is to secure the reproduction of the plant. The seed contains, in addition to the embryo or rudimentary plant, a store of plant food for its early supply. This reserve contained in the endosperm (as distinct from the embryo) of the seed constitutes, in the case of barley, over nine-tenths of its entire bulk and consists almost entirely of cells densely packed with starch granules.

There is no correlation between weights of embryo and endosperm, and yield does not depend on the weight of the embryo. Weights of embryos and/or endosperms are generally subsidiary factors and moreover bear fluctuating relations within races.

Some races of barley have larger endosperms than others and are therefore able to provide a greater quantity of nutritive material for the development of the young plant. The physical and chemical components of the endosperm are much more important than size and these fluctuate within races with environment. Such characters as these, and even the vitality of the embryo, have little relation to actual size. Such influence as they have is only on the prolificacy of the individual plant and this is only one, and often not the most important, racial factor of yield per acre. The composition of the endosperm in respect of the ratio of nitrogenous to carbohydrate matter, and in other respects, is to some extent a genetic character.

But within the same 'pure race' [1] there may be still wider fluctuating differences in the seed. Every farmer knows the necessity of sowing grain which has been well harvested and

[1] 'Pure race' is a term used to denote descendants of a single self-fertilized individual and does not, as the word 'pure' would seem to imply, refer to constancy (or purity) of the individuals of the race, or line.

which has passed through the resting stage since harvesting under conditions which do not impair its germinating power.

The germination of grain is a biological process and the limitations are therefore very great. Organic material is never homogeneous—both in the plant and in its ultimate product, the seed, there is variation in every direction. The process of germination varies very widely with soil conditions; to some extent with different races of barley; to an even greater extent with the fluctuating characters of the seed; and with the period of sowing. In very many seasons, in England, barley germinates more freely if sown in February than if sown in April, by which latter period the embryo may have passed its period of highest vitality.

With regard to the respective value of large and of small grains of the same race, it is possible that a large grain with a dry weight of 50 mg., of which 80 per cent. will be endosperm, and containing 6 mg. of proteid matter, is able to provide the young plant with more assistance in its early struggle for life than a grain of half this weight. Barley grains of the same race, as a matter of fact, range in weight between these extremes, but I have found that a much smaller range of fluctuating variability of weight and composition, such as is often due to the conditions under which the grains on the parent plants have matured, makes a marked difference to the germination and development of the young plant.

Experiments made at Warminster in 1911 illustrate the fact that when young plants of the same 'pure race' of barley are in competition for soil space there is marked advantage to those grown from grains with large and nitrogenous endosperms. The grains used in this particular experiment were all from the same 'pure race' of Archer barley: all originating from a single plant in 1901.

The table on p. 30 shows that tillering (avg. no. stems per plant) in barley is partly dependent on the grain. The grain provides nutriment to the young plant for the first few weeks of its life up to about the time when tillering may commence. A readily available supply of nitrogenous matter from the grain is available, and the larger nitrogenous grains produce the most tillers when there is equal soil space per plant.

It will be seen from the table that there was wide variation in the weight and composition of the seven parcels of grain

TABLE I.—Averages of 200 Plants, 12 Plants per square foot, planted in alternating rows of 12 Plants

	N. per cent. of dry grains	Weight per 1000 grains (grammes)	N. per 1000 grains (grammes)	Average no. stems per plant ('tillering')
A1	1·79	38·5	·690	1·67
A2	1·47	43·9	·646	1·56
A3	1·66	34·2	·568	1·53
A4	1·51	34·4	·518	1·41
A5	1·45	31·8	·460	1·33
A6	1·32	32·8	·433	1·40
A7	1·40	23·0	·322	1·19

used. This range was due to two different sets of conditions. The grains for A1, A2, A3, A4 and A5 were taken from 5 bulks grown in various localities in 1910, but all originating from a single plant in 1901. The grains for A6 and A7 consisted of screenings from A2 and A3. A2, A5 and A7 were originally part of one parcel, but were separated by dividing the parcel into grain of three different weights per 1,000 grains.

A row of 12 grains of each parcel was sown in the order shown in the table and the seven rows were repeated in the same order twenty times. There were therefore 140 rows of 12 plants each. About 10 per cent. failed to produce mature plants. The average number of stems per plant was recorded for each row and after ripening the ears of each row were weighed separately.

The 'probable error' of the seven averages, due to irregularities of the soil and cultivation on this small plot, is not more than 2 per cent. of any of the averages, and it is quite obvious that there is a significant correlation between the proteid matter in the grains and the number of stems of the resulting plants.

It is not, however, to be assumed that differences comparable to this would be obtained in ordinary farming practice. A farmer does not sow a given number of grains on unit area, but a given weight of grain. If a farmer had

been sowing parcels of both A1 and A7 on different fields at the rate of 140 lbs. per acre (the usual 'seeding' rate in England) there would have been about 340 grains per square yard of A1, and 570 grains per square yard of A7. Few farmers would use grain as small as this latter sample. At harvest it is quite possible, however, that there would be approximately the same number of plants on each area. The number might be anything between 70 to 120 plants per square yard, according to the cultivation and the season. The remaining grains would either not have germinated or would have been crowded out.

Also under some conditions a greater number of surviving plants might outweigh the advantage of stronger individual young plants. Whether or not this is so, it is certain that the development of the individual plant is very considerably affected by merely fluctuating characters of the endosperm of the seed within the grain; and in many sets of conditions this might be a determining factor of ultimate productivity.

This result has also an application to experimental work and especially to 'variety testing' of cereals, and to some methods and conclusions of plant breeders. It may also have some bearing on the prevalent opinion amongst growers in favour of a 'change of seed' and their preference for seed-corn from other localities than their own. The persistence of this practice is some evidence that benefit often arises. It is almost inconceivable that it arises from mere 'change of air', or to the latitude and longitude of the source. It must be due either to the composition of the true seed due to the environment in which it was grown, or to racial characters. No other reasons can be assigned with any degree of probability.

The young plant is largely dependent for its early supply of nitrogen on the endosperm of the seed, and it follows that those plants which are supplied with sufficient nitrogen by the parent seed at this stage make the best start. In the competition which subsequently takes place, plants with adequate initial nitrogen supply will survive and those with inadequate supply will perish. A supply of nitrogen to a growing plant is as essential as a supply of moisture.

I think, notwithstanding some opinions to the contrary, that in this country, at any rate, it is generally better practice

to sow a given weight per acre of large nitrogenous grains rather than of small starchy ones.

The nitrogen content of the 140 lbs. of seed barley usually sown on one acre may be as much as 2·8 lbs. or as little as 1·6 lbs. The whole of the nitrogen is not available for assimilation by the young plant. A considerable proportion of it is contained in the aleuron cells and this structure is very resistant to the enzymes which degrade the matter into assimilable forms. But the nitrogen of the starch-containing cells of the endosperm is known to break down quite freely into food for the young plant, and the average quantity of nitrogen in this form contained in 140 lbs. of seed may be somewhere about 1 lb. This is approximately the quantity of nitrogen which will be found in the young plants on an acre of ground when the first shoots are about two inches in length above ground and when the plants are just beginning to start 'tillering' and to make adventitious roots at the bases of the tillers. Some of the nitrogenous matter of the endosperm may be washed out, if the soil is wet, before it is taken up by the young plant, but from some laboratory experiments made I have found that this does not occur unless the soil is *very* wet. It is probably part of the function of the aleuron cells forming the circumference of the endosperm and of a membrane surrounding it (which is the remains of the testa of the seed) to retain the soluble proteid for the use of the embryo plant.

I have found that the total nitrogen of young barley plants at the period when the adventitious roots are beginning to appear (which may be a period of three to four weeks after sowing) is frequently less than the nitrogen content of the grains from which they grew.

In England the samples of barley which have the lowest nitrogen content are those which are of the highest quality for the purpose of malting. It would appear therefore that barley which is best for malting in respect of the composition of the endosperm is not the best for sowing, but it is not difficult in practice to secure comparatively high nitrogen in any race of barley. The cultural conditions necessary are very thin seeding, say, about 50 lbs. per acre on rich soils. The result in respect of quality of grain, even in this case, is of course considerably dependent on climatic conditions. In

England these cultural conditions almost invariably result in a heavy crop of large grain of comparatively high nitrogen content, coarse in appearance and of low malting value, but subject to good harvesting and storage conditions of higher intrinsic value for sowing than barley grown under normal conditions with a view to good malting quality.

The idea that it is desirable to sow grain which has the characters associated with good malting quality is probably based on the assumption that this quality is transmitted to the crop. In so far as the 'quality' of the grain is a racial character it will be transmitted, but there is no evidence that the fluctuating quality due to the environment of the parent plants is transmitted. Only the racial or genetic characters are persistent, and, in the case of barley (unlike wheat), the composition of the endosperm is to a far greater extent determined by environmental conditions than by racial character, with the result that such differences in the proteid/carbohydrate ratio of the endosperm as are inherited racial characters are in practice overwhelmed by the cultural conditions in any one generation.

Generally speaking, the barley grower will do best to start with a race known to be prolific or a race known to give good quality, preferably both; in fact a barley which is suited to his average conditions of soil and climate; and then in each year to grow for his own use as seed, say, 5 per cent. of his total area, under such special conditions as are likely to give good seed-barley rather than barley of good malting quality. The question of seed testing should be studied by every practical farmer.

If I were growing barley for sowing purposes I should be inclined to grow a few acres and endeavour to obtain as large a grain as possible. Grain of a 'pure race' which is large, and even coarse (providing that the coarseness is not a character of the race but the result of manuring or thin seeding), is preferable to a small grain of the same race for this purpose and gives the young plant a better start in life.

Growing six-rowed barley as a forage crop, a coarse nitrogenous grain is as good, or better, material for seed as a mellow 'kindly' grain.

The function of the primary root system in barley appears

to be mainly to provide a transpiration current as part of the mechanism of transference of the reserve food material of the endosperm to the young plant.

If a young plant of barley is taken up just about the time when branching side shoots begin to appear at the first node, it will be noted that the primary root system is tough and fibrous and has little soil adhering to it. If the soil conditions have been favourable, a few adventitious or secondary roots are seen springing from the first node, and these are abundantly covered with root hairs to which soil particles closely adhere. The plant is commencing the second, or vegetative, stage. From then onwards the function of the stored nutriment in the endosperm of the seed, and also of the primary root system, diminishes and, given favourable soil conditions, that of the secondary root increases: the result is a continuous increase in the total weight of dry matter. This increase, if external conditions are favourable, goes on in approximately arithmetical progression until seed formation is well advanced. There appears to be no doubt that this is a critical period in the life of the plant, as is the somewhat parallel weaning time in the life of an animal, and races differ widely in behaviour in this period, and also in that of the seedling stage.

When, as under the usual field conditions, there is considerable overcrowding of the individual plants, a large number perish at this stage. With average rate of seeding, with about 300 barley seedlings per square yard, approximately 100 only survive throughout the vegetative stage to produce grain.

If the grains sown are all of the same 'pure race', or are homozygous in all the characters important to the plant at this stage, the conditions which determine the number of plants which will survive will be mainly those fluctuating endosperm characters already referred to and which have given some plants a better start than others. There is no evidence which leads to the supposition that the selection which takes place will have any effect on the character of the aggregates. The case is obviously different if we have an aggregate composed of more than one race, such as 'Scotch Common', or 'Old Irish' barley.

There is in cultivated barley a very wide range both of

fluctuating and genetic variability in this vegetative or accumulative stage.

The solid matter of the plant is derived from the soil and the atmosphere in very unequal proportions. The soil contributes the whole of the nitrogen and mineral matter, but with barley these two together only amount to about 5 or 6 per cent. of the total dry matter of the ripe plant. This 5 or 6 per cent. is, however, absolutely essential to the formation of the remaining dry matter of the plant, which consists originally of carbohydrate matter, formed mainly in the leaves by the combination of elements contained in air and water. The absorption of this 5 or 6 per cent. of nitrogen and minerals, along with a sufficient amount of soil-water and of the elements of water in combination, is the work of the root system of each individual plant.

The total weight of dry matter of the plant may be anything up to two tons per acre, and with a combination of prolific races and suitable climatic conditions it may be in rare cases as much as three tons.

With regard to the genetic characters affecting accumulation of food material from the soil and the atmosphere during the vegetative stage of the life of the plant, there are tall and dwarf races of many plants and, other characters being equal, *a priori* the tall race will accumulate more dry matter on a given area than a dwarf race. There are tall and short races of barley and, other things being equal, the tall race might be expected to have the higher accumulative power, but a tall race of any of the cereals under many climatic conditions, and especially those of Great Britain, runs the risk of 'lodging'. The normal processes of accumulation are impossible if the plants are lying on the ground, and are hindered to some extent when the stems are leaning. The races which I have found to accumulate the greatest weight of dry matter in average seasons are neither the tall nor the very short races.

The length of the growing period is a genetic factor, and the races which have the longest growing period consistent with arriving at maturity in seasonable time are generally those which make the highest accumulation.

Some time (varying with the climate) before the grain is ripe the plant ceases to gain in weight of solid matter. This

is the third and final stage in the life of a cereal plant. At the same time there is going on a migration of the plastic reserve material accumulated in the stems and leaves upwards to the endosperm of the seed. The plant is then providing for the nutrition of its offspring and its last effort is to transfer its accumulated reserves into the grain, for it is on the material accumulated in the endosperm of the seed that the young plant of the next generation will mainly live for the first two or three weeks of its life, and these are critical weeks. Barley is a more efficient starch factory than any other species of the *Gramineae.* This is true even of wild barley (H. *spontaneum*). They say in Norfolk 'Barley is a gentleman'—meaning that it requires and deserves kind treatment. Barley is also a good mother: it stores up to start its offspring in life a larger proportion of its own substance in its endosperms than does any other cereal plant, and, I believe, more than any other cultivated plant. It is because the barley plant transfers so high a proportion of its total weight, in the form of starch, to its endosperm that it is the best cereal for brewing.

The yield of dry grain, as distinct from the total weight of the entire plant, depends on the effective transmission of the material accumulated in the leaves and stems of the plant. If, owing to any conditions of the plant, external or internal, this process partially fails, there cannot be a good yield of grain, however thick the plant may be and however favourable may have been the earlier vegetative conditions. There may be plenty of straw for cattle, but little grain for the use of man. A part of the material which might have added to the weight of the grain is left behind in the straw.

It is no exaggeration to say that this 'migration', this 'uplift' of the grain-forming materials from the leaves and stems of the plant into the grains of our cereals, is for the cultivated races the most portentous of all the processes of nature. It is mainly and predominantly on the extent to which this 'uplift' takes place that plenty, or scarcity, of the staple food of man depends.[1]

To take one season as an example of the disastrous effects of adverse conditions on this process, as showing the relation

[1] Some research on the subject of the physiology of migration was carried out at Rothamsted by Dr. W. E. Brenchley, and the results published (1909).

of physiology to practical agriculture: in 1920 in this country numberless fields of wheat and barley, especially in the Midlands and West of England, which before harvest looked very heavy, and which in many cases made more and bigger stacks than usual for the same area, gave under-average yields of grain per acre.

In this matter good or bad farming is quite subsidiary. A sufficient plant in late spring depends, in this country and in most seasons, mainly on fertility of soil and skilful cultivation. But this factor of migration, which is the expression and the result of the seed-forming energy of the individual plants composing the crop and on which yield per acre predominantly depends, is for the most part dependent on a due balance between sunshine and rain.

So it is that the farmer, especially if he is something of a pessimist, meets the agricultural investigator with the remark: 'That's all right, but God's weather will beat you every time'.

But if the external conditions are the predominant factor, the structure of the individual plants has also something to do with this process. I have already referred to the root system, and I have accumulated enough evidence to demonstrate that there is very marked variability as between different races in the appearance of the root system and in the ratio of weight of root to weight of plant, especially in the earlier stages of growth. Some of the best yielding races, and those which ultimately show in average seasons the best ratio of grain to straw, seem to be those which start out in life by making during the first six to eight weeks of their life more root and less stem than the lower yielding sorts. This is a characteristic of the 'Archer' type of barley.

The root system of barley varies genetically in quantitative characters in relation to the above-ground structure, but these variations are generally so completely masked by fluctuating variability as to be difficult of observation.

There is doubtless as great, or greater, difference in underground as in above-ground growth under different soil conditions. It is quite conceivable that with different races of barley there may be tendencies to special characteristics of under-ground development, and not improbable that these may have even more to do with the ultimate quality of

the grain than the character of the above-ground vegetation. This especially applies to winter sorts, where a considerable root range is reached before much vegetation appears.

In May 1909 a series of determinations was made on root/plant ratios at the Warminster station on plants of two races (Archer and Plumage) at 50–55 days from seeding. The results are given in Tables II and III.

The conclusions which can be derived from these tables are:

1. With both races there is very wide variability in the factors of productivity.

The rate of seeding was 2·5 bushels (=140 lbs.) per acre and weight per 1,000 grains was 45·36 grammes at 16 per cent. moisture (=38·2 grammes dry matter).

The number of grains sown was therefore about 1·4 millions per acre (=290 per square yard). The number of plants of both races surviving to harvest 50–55 days from sowing (i.e. mid-May) was 266 on 24 sq. ft. (=100 per square yard=484,000 per acre), equal to 34·5 per cent. of the grains sown. It is fairly certain, however, that the survival rate was less than one-third in some cases and more than two-thirds in others. The percentage surviving to harvest at, say, 150 days from date of sowing would, of course, in this case be less.

From numerous reported counts of plants surviving to harvest it may be estimated that with average crops yielding 16 *cwts. grain per acre the number of grains sown is about* 300 *per square yard and the number of plants surviving to harvest between* 75 *and* 90 *per square yard. If this is so, it means that the number of plants harvested is only between* 25 *and* 30 *per cent. of that of the number of grains sown. This fact obviously provides opportunity for 'survival of the fittest', or of any 'viability' factor.*

A yield of 16 *cwts. grain per acre is equivalent to* 0·37 *lb.* (=168 *grammes) per square yard. The average number of ears per plant with a* 16-*cwt crop will be generally less than two under normal conditions of cultivation in Great Britain and the average number of grains per ear may be anything between* 18 *and* 24, *and the average about* 21, *containing* 16·0 *per cent. water and weighing* 0·0475 *gramme per grain* (=1 *gramme per ear*).

As between the two races sown the average plant population for 12 sq. yd. counts of each was Archer 10·1 and Plumage 12·1 (avg. 11·1). For such a small number of cases this difference is not significant. It is as likely as not to be due to irregular seeding, which occurs with all drills; and/or to soil conditions.

TABLE II.—Roots washed out from soil to a depth of 9 inches: Archer Plants

Days from sowing	No. of plants per sq. ft.	Average dry weight per plant, including root (grammes)	Weight dry root per cent. of plant
	(1)	(2)	(3)
54	7	1·67	14·8
55	7	1·42	22·6
50	8	0·75	30·5
54	8	1·06	22·9
53	9	0·86	19·9
55	9	0·81	16·0
53	10	0·84	22·3
54	10	0·98	27·0
55	12	0·81	14·9
55	12	0·70	19·0
55	13	0·90	18·6
53	16	0·68	28·4
Averages	10·1	0·96	21·8

TABLE III.—Roots washed out from soil to a depth of 9 inches: Plumage Plants

Days from sowing	No. of plants per sq. ft.	Average dry weight per plant, including root (grammes)	Weight dry root per cent. of plant
	(1)	(2)	(3)
50	7	0·71	14·1
54	7	0·71	9·0
55	7	0·97	17·2
55	7	1·01	19·5
54	9	1·10	15·2
54	11	1·06	12·4
55	11	0·74	15·4
55	12	0·94	16·3
55	14	0·67	15·3
53	15	0·47	18·8
53	17	0·47	19·8
53	28	0·71	14·3
Averages	12·1	0·80	15·6

NOTE.—The number of plants per square foot for both races ranges from 7 to 28, averaging 11·1. The differences shown in the last column (3) between the percentages of root to plant are as definite and consistent as can be expected when the difficulty of extracting the roots intact from the soil is considered.

2. The average dry weight of all the 266 plants is 0·88 gramme.

Judging from many other records the probable dry weight of the plants which survive to harvest would be about 4·0 grammes per plant. Those which perished from overcrowding would generally be the smaller plants. In the Warminster nursery chequer-board cultivations the average dry weight of over 300,000 plants at harvest was 4·2 grammes per plant.

There is a significant negative correlation (as would be expected) between the number of plants per square foot and the dry weight per plant. Crowded plants at this stage make less growth per plant than those with more soil space per plant.

The average dry weight of crowded plants was significantly less than that of those of the same race with more soil space, at the same age and growing in approximately similar environment. This is obviously what might be expected. It is indeed probable that the negative correlation between soil space and weight per plant would be very high either in a much larger sample, or under precisely similar environment, which is not attainable in any field for any two square feet of soil, however nearly adjacent.

3. There was no correlation between number of plants per square foot and the root/plant ratio. The average ratio was approximately the same with 7 to 9 plants per square foot as with 10 to 16. But here again the sample was much too small for any conclusion as to what would have been the case with a much larger sample.

Assuming the square-foot areas of the races to be adjacent and similar in soil character, then it appears that high root/plant ratios of Archer are probably associated with low root/plant ratios of Plumage; but that with low root/plant ratios of Archer there is as often as not about equal root/plant ratios of Plumage.

With both Archer and Plumage there is no significant correlation between dry weight per plant and root/plant ratio. Low weight plants (i.e. those with few tillers) have about as high a root/plant ratio as higher weight plants, indicating that root and shoot develop *pari passu* in both of these races, the extent of both depending on extrinsic (environmental) conditions.

With regard to the stems and leaves of the plant, the most

superficial observation shows that there is very wide variability as between races. There are wide genetic differences in the character of the foliage and in the ratio of leaf to stem but, as far as I know, there is no evidence that the total accumulation is related to these differences. Stems are short or long, thick or thin, tough or brittle in the neck, and as a consequence in some cases maintain a much more upright growth than others. There must be some connection between liability of a crop to 'lodge' and the inherited structure of both the root and the stem. When the plant gets to the stage of transferring its accumulative reserves into the seed, manifestly the structure of the stem is of the first importance. This migration has to go on through certain vessels specially adapted to the process which carry up the material in a fluid or semi-fluid form. It can only go on whilst the plant as a whole is alive, and the life of cereal plants is dependent on at least some absorption of water by the roots for the maintenance of what is known as the 'transpiration current'. It is quite clear that this process is interfered with if the individual stems before they are fully ripe are either 'lodged', or bent at the nodes, or neck-bent.

It seems probable that races with short and stiff stems, well anchored to the soil by strong and vigorous roots, should have the best 'migration coefficient' and, other essentials being equal, should give the highest produce of grain.

With regard to the structure of the stem and its vessels, I well remember listening to Mr. John Garton lecturing at Salisbury, some time in the early nineties, when he and the great seed firm with which he was associated were giving a lead in the application of cross-fertilization to cereal breeding in this country. Some of the most striking of Mr. Garton's magnificent enlarged micro-photographs, illustrating the structure of cereal plants, were those which showed the variations which occurred in the arrangement of the vessels of the stem, and there is no doubt that these are inherited characters.[1]

[1] The relations between the vascular system and the habit of growth of different races of barley have not been investigated: such an investigation might lead to useful results. Some races, such as those of the H. *hexastichum* sub-species, which are winter-hardy in this country, have vascular systems which are distinctly different from those of races of H. *distichum*, and they have perhaps in consequence a much more erect habit, and this is an important economic factor.

Remembering that practically all the material which goes to make the seed is first of all built up in the leaves of the plant it is obvious that the structure of the leaves is as important, if not more so, as that of any other part of the plant. No systematic attempts have been made to relate leaf structure to yield, or even to the process of migration. This, however, obviously is a fruitful subject for research.

There are nearly always the same number of leaves on each stem, but the size of the individual leaves, and probably therefore their individual capacity to elaborate material to be ultimately transferred to the grain, is very variable as between different races. The longest leaves are generally borne by those races which have the thickest and shortest stems. In my experience, although these races are not always the best 'tillerers', they make up for this by producing heavier ears and larger grain. The shape of the leaves in respect of relative length and width is subject to considerable variation both genetic and fluctuating. There is very little data available on which to base conclusions as to relative values of such factors as much or little leaf structure, for economic purposes.

The filling up of the grain, which is only effected by good migration, depends on the health of the plant being maintained.

Evidently all the structures of the plant and the conditions of its life will affect the migration of the reserve material into the seed. For maximum migration the requirements are an effective root system, an effective set of vessels in the stem and comparative immunity from disease. If either condition is lacking the plant fails in making its final effort. The ratio of grain to straw, expressed for convenience as the 'migration coefficient', is the measure of its success.

When cereal crops are grown for grain the value of the straw is inconsiderable compared with that of the grain, and this applies to barley more than to wheat or oats.

In some countries, e.g. some parts of Australia, New Zealand and California, where barley is grown as a hay crop, and even in some parts of England, viz., in some of the corn and sheep districts where barley is grown for green fodder, the migratory stage, if reached at all, is relatively unimportant.

The ratio of vegetative to seed-forming energy is another

important point. Excess in one direction may mean relative failure in the other. A high ratio of vegetative to seed-forming energy, causing over-development of the paleae, almost invariably results in a coarse and steely grain with a high nitrogen content. The paleae (husks) are no part of the seed proper. They are leafy structures provided with stomata, and doing part of the work (perhaps in the later stages a relatively considerable part of the work) of assimilation. But the paleae limit, or at any rate condition to some extent, the development of the seed. The starch-containing cells of the endosperm multiply and develop from the centre outwards and they mature in the same order. This is shown by sections of ripe and unripe barley. The white mealy zone extends from the centre outwards. The pericarp of the caryopsis and the paleae adhering to it, as well as the testa of the seed, are already complete in structure before this stage begins. There is therefore great pressure from within outwards. This is why the pericarp and testa collapse into mere membranes hardly recognizable in the ripe seed, and is probably why they become attached (except in the naked forms) to the paleae. But the paleae are much more resistant than the pericarp and testa of the grain. They do not collapse as do the inner envelopes and so the stronger and tougher the paleae the less they accommodate themselves to the growth of the endosperm.

CHAPTER V

PEDIGREE SEED-CORN

Effects of Natural Selection

Formerly a considerable proportion of the seed-corn used in the United Kingdom consisted of mixtures of many varieties. In some parts of the country these mixtures resulted in aggregates of more or less well marked types, such as 'Scotch Common', a hardy barley with a short-growing period, grown north of the Tay (generally grown to-day in N.E. counties of Scotland); and 'Old Irish', grown in some parts of Ireland in small quantities (now principally in Wexford) and in some outlying Welsh districts. Such similarity as these local mixtures presented was doubtless the result of the exchange of seed-corn being generally limited to the district, or to prolonged cultivation under approximately similar conditions. In other words, these aggregates became what they were mainly by the action of natural selection. We may call them 'local varieties', at the same time remembering that the term 'variety' has no precise definition. Barley of this class is known in Germany as 'Landgerste' (i.e. the barley of the land) in contradistinction to 'Chevalier gerste', 'Goldthorpe gerste', etc., for varieties of which the origin is known and the characters well defined.

Local varieties have been replaced in the large corn-growing districts by a large number of distinct varieties and more or less 'pure lines' of each of the cereals, differing from the former in that the individual plants composing the several aggregates are much more uniform. There is, of course, a constant tendency for these stocks to get mixed. At the same time, it must be admitted that some of them differ from others in little more than name. Most of the distinct varieties and 'pure races' of the cereals at present in cultivation are the progeny of either single plants selected originally from local varieties or mixed races, with or without resort to artificial crossing. The method of raising a stock from a

selected individual plant (of a species which is normally self-fertilized), without artificial crossing, gives rise to a 'pure race', the individuals of which (apart from such accidental mixture as is inevitable, or from 'sporting', which is very infrequent with cereals under normal conditions) differ only in consequence of the effects of external conditions, which do not affect the racial character of the stock.

A plant, or plants, selected from the progeny resulting from a cross may or may not give rise to a uniform 'pure race', according as the plants selected are or are not homogeneous in respect of every structure of the plant in which there was dissimilarity in the original parents, or, stated more simply, are 'fixed' in respect of all characters.

There is no advantage from the point of view of growers in putting into cultivation new races unless they are superior to old races, and from the point of view of millers, maltsters and other grain consumers, multiplication of sorts is a disadvantage. There are certain well-established standards of quality associated with existing varieties or races, and undue multiplication leads to confusion. In the interests of both growers and consumers, the existing races best suited to the different localities and soils should be adhered to until superior ones are discovered.

That there are very substantial differences in average yield as between existing races of cereals in particular localities is well established. In any particular locality, and for the same type of soil, a jury of growers would probably give a unanimous verdict that certain named races were in average seasons better yielders than others.

There is less unanimity with regard to the average quality of the grain of different races, because in the valuation of this the knowledge, or even perhaps in some cases the prejudice, of the consumer comes in to complicate matters. Modified processes of manufacture also lead from time to time to altered values being put upon different grain characters.

The subject of the adaptation of certain races to the climate and soil of a particular locality is of very great interest. It is also very complex, and our knowledge on the subject is almost wholly empirical. A grower has frequently no *a priori* knowledge to indicate whether any new race well spoken of in some other district is likely to

give good results on his land. Definite evidence is needed of the suitability of varieties and races to locations and soils, and in this connection the cumulative effect of natural selection in modifying the racial character of the cereals must be taken into account.

In some cases experience has led to a fairly definite conclusion that some existing varieties or races of each of the cereals are, and some are not, adapted to particular soils and localities. Spratt, one of the oldest kinds of barley in cultivation in Britain, is a typical case of the adaptation of variety to a particular type of soil. It has a stiffer straw than most British barleys and gives very heavy yields on rich loamy soils, often more than compensating for the usual low quality of the grain. Whilst it was grown successfully in the Fens (and still is to a certain extent) it has been found to be out of place on soils well adapted to grow good malting barleys. Similar cases with other cereals are known to every corn grower.

This accumulated experience, however, takes a long time to gain. Moreover, with the introduction of systematic methods of hybridization there is proceeding considerable increase in the number of races of cereals. However good in various respects as to special characters these new sorts may be, they are unlikely to be profitable unless it can be definitely established that they yield as well as, or better than, older sorts.

The climatic conditions of districts vary so greatly from year to year that one or two years' experience is useless. For instance, Goldthorpe barley was a success for some years in North and East Norfolk, but in one dry season some years ago there was a widespread loss of crop owing to ears breaking off—the common failing of many wide-eared sorts. On the other hand, this class of barley did well in Shropshire, in Scotland, and in Yorkshire. Much better comparisons can be made of both yield and quality between distinct varieties and 'pure races' than between aggregates of fluctuating composition.

A large number of 'variety tests' of cereals have hitherto been carried out by public bodies in various parts of England, but they have generally been too isolated and not prolonged enough to be of practical value to the growers. In other

countries, notably in Denmark and in Ireland, very exhaustive and efficiently organized trials of barley have been in operation —for about fifty-five years in Denmark and forty years in Ireland. The marked improvement in barley yields in Ireland from this period is an example of success due to these systematic yield trials. In this country, since 1926, the National Institute of Agricultural Botany has tested by systematic and repeated trials in six different corn-growing areas, at Cambridge and at five sub-stations, the relative merits of different races of farm plants. These trials have demonstrated conclusively that there are very wide differences in farming value, due either to yield or quality, or both, as between different races of the same species of cereals grown under identical conditions, and no doubt the same applies to other farm plants. As years go on and a very large number of comparisons are available, each, owing to the method of trial, known to have a negligible experimental error, it will be safe to make definite pronouncements. Some few have been made already in the Annual Reports of the National Institute of Agricultural Botany, and there is conclusive evidence—at any rate with regard to barley—that some new races which have done well in the Institute's trials have proved also to be valuable additions to the farm plants of the country.

The late Mr. J. B. Gill, the enterprising secretary of the Essex Farmers' County Union, co-operating with the above Institute, collected records from farmers for the years 1926–29 of different races of the cereal crops harvested, in each parish, in that county. The figures were examined and arranged by the staff of the National Institute of Agricultural Botany and the results published.[1] If this scheme could be revived and further extended to other counties it would form the basis of a body of statistics which could be usefully interpreted, and prove no doubt to be of as much value to corn growers as milking records have been to dairy farmers.

In this connexion I would refer my readers to an old *Bulletin of the Experimental Station of the State of Indiana*, showing that as long ago as 1905 an extraordinarily good system was elaborated whereby in different areas of the State there were distributed to a large number of farmers

[1] *Jrl. Nat. Inst. Agrl. Botany*, vol. ii, pp. 142 and 232; and vol. iii, p. 236.

four or five different varieties of maize year after year. From the results obtained from the growing of these varieties a mass of statistics was collected, the interpretation of which was of great benefit to the farmers of the State. A description of this method and the tabulation of some of the results obtained will be found in a paper entitled 'Pedigree Seed Corn' (1909).

Change of Seed

There are endless differences of opinion as to the advantage of 'change of seed', that is of seeding a given race in a different soil or climate from that in which it was grown.

In the absence of any very definite evidence on this point it is difficult to form a judgement. A general principle would appear to be that, so far as robustness of vegetation is concerned, when the soil and climatic conditions are better than those in which the seed was reared an improvement may be expected. So that it would seem desirable, where this is the result desired, to transport seed from a cold to a warmer climate, and from poor soils to superior ones, rather than the reverse.

Mixed Seeding

There is a good deal to be said in favour of sowing 'mixtures'.

In 1909, in the *Agricultural Gazette* [1] there appeared some interesting references to the sowing of 'mixed wheats'. One writer adduces the results of practical experience in favour of the practice, and justly gives as the reason in its favour that 'all varieties have naturally different requirements', and that a mixture has the advantage of 'utilizing more thoroughly the resources of the soil'. Professor Wrightson commenting on this agreed on general grounds, specifically mentioning a mixture of 'Lincoln Red' and 'Squarehead's Master'. Both authorities, however, infer that the mixtures should be designed and not merely accidental, and the isolation of distinct varieties and some knowledge of their several habits is therefore postulated.

Mixing varieties and even species of the cereals is very ancient agricultural practice all over the world. In many

[1] *Agricultural Gazette*, November 1, 1909, p. 418; *ibid.*, November 22, 1909,

parts of India nearly all the grain crops to this day consist of mixed species of cereals.

Very many of our best-known agricultural ancestors believed in mixtures. Thorold Rogers (1866–1902) finds frequent reference in the bailiffs' accounts to 'drage' and 'drage malt' in Manor Rolls of the thirteenth century and onwards. 'Drage' was evidently a very commonly grown crop, and although Rogers considered it to be an inferior kind of barley, it is certain that it was really the same mixture of barley and oats which is still called 'dredge' corn in the south and west of England. I think there is no doubt that under equal cultural conditions this mixture produces heavier yields of both grain and straw than either barley or oats grown separately.

On the subject of mixing different varieties of wheat, more than two hundred years ago Lisle, in his *Observations*, wrote: 'Mr. Johnson of Bedfordshire, of whose judgement I have a great opinion . . . was (under certain conditions) inclined to sow great wheat and red-straw-wheat mixed, that the former might help to support the latter from lodging and falling'. And Lisle adds: 'I have known great wheat and red-straw-wheat often sowed in the north in good land, for the same reason' (pp. 151–152).

John Wilson (1859) records the case of an experiment with wheat carried out by M. Lucien Bousseau of Angerville. Fifteen different varieties were sown alongside, and on a sixteenth plot was sown a mixture of all the fifteen sorts in equal proportions. This plot, he says, gave a much higher yield than either of the others. Vilmorin's comment on this result (and there was no better authority) was that such a result may be expected if care is taken in the original selection of the varieties to be mixed. This, of course, involves breeding 'pure lines', just as it is necessary to maintain the thoroughbred horse and the breeds of sheep which give the best results with cross-breeding.

Wheat and rye were often sown together and bread was made from the flour, called 'Maslin' or 'Meslin'. There are few crops of this in England now, but it is still grown to some extent in Germany and Canada.

There seems no doubt that mixtures of different species very frequently yield a greater total produce on a given area

than would either of the species alone. The same may hold good of mixed varieties or races of any one species when compared with seed of a 'pure race', unless the latter has been bred with special reference to the average external conditions of the locality.

There is, however, a great difference between (1) a designed mixture of varieties, and (2) the aggregate which results either (*a*) from natural selection in a district where 'pure races' have not been introduced (e.g. Scotch Common barley), or (*b*) from indiscriminate mixtures of 'pure races'.

A good deal of the seed-corn used in some parts of England hitherto was of the latter class, and this state of things comes about more particularly in districts where one 'type' of barley is found to be generally suitable, but where this type is represented by a number of distinct races which, possessing different racial characters affecting prolificacy, yet closely resemble each other in appearance, sometimes when observed as plants, and even more frequently when observed only as grain. For instance, the barley grown in Yorkshire was formerly nearly all of the wide-eared type, but this type is represented by at least half a dozen well-known races, some (Goldthorpe for one) known to be raised from single self-fertilized plants; others (like Standwell) resulting from cross-fertilization in the first instance. There is very little doubt that a considerable proportion of the seed-barley formerly used in Yorkshire was a mixture of these different, though externally similar races.

Chevalier and Archer barleys were frequently found mixed, although in this case there is a distinct structural difference in the grain (to say nothing of the generally obvious difference in the straw) which entitles the two sorts to be classed as two distinct varieties. This particular mixture was not likely to give good results in most seasons. Archer has about a week longer growing period than Chevalier, and even ripening is of great importance with barley.

Effects of Natural Selection

It is interesting to consider what happens when mixtures of different races are sown, and seed-corn taken in successive years from the previous crop.

It is evident that the character of the resulting aggregate after some years depends mainly on such natural selection as goes on in the field. The effects of natural selection on the racial character of our cereals is worthy of more attention than it has hitherto received.

Let it be assumed that only one of four grains sown reproduces grain. This will be the case with barley if the crop of grain is twelve and a half times the quantity of grain sown, and if the average number of grains on each plant producing grain is fifty: a sufficiently near approximation to average field results.

Let it be further assumed by way of example that there is sown a mixture composed of 25 per cent. each of four distinct races, A, B, C, D, and that the resulting crop shows the above ratio of crop to 'seed', viz., 12·5 : 1.

The four races will certainly differ in cropping capacity. If planted separately it is probable that the extreme difference in weight of grain on equal areas would not be more than 10 per cent., but with very severe competition involved in the obliteration of three out of four grains or plants at some stage between sowing and harvesting, and taking into account the inevitable differences in adaptation of the several races to the conditions of soil, climate and cultivation, it might well happen that the ratios of grain harvested to grains sown might be A, 5 : 1; B, 10 : 1; C, 15 : 1; D, 20 : 1; giving 12·5 : 1 as an average. If the average number of grains produced by each surviving plant is fifty, a ratio of even 20 : 1 for the most vigorous race means that more than half the grains, or plants, of even this race have failed at some stage.

If the grain is taken from the resulting aggregate and resown, and the process continues under the same conditions and with the same ratio of reproduction for each race in each year, a simple calculation shows that in three years A, instead of forming 25 per cent. of the crop, will be represented by less than 1 per cent. In six years B also will be reduced to below 1 per cent. of the whole, and whilst A may remain to the extent of only about five plants per acre, C will survive considerably longer. At the end of fifteen years the total of A, B and C together will be less than 1 per cent. of the crop, A and B being then almost obliterated. The crop will be practically a 'pure race' of D.

Even if the ratios of reproduction of different races are only slightly different, the same result will occur if the ratios are steadily maintained, and sufficient time elapses.

Suppose, for instance, the average ratios of grains produced to grains sown be A, 12 : 1; B. 13 : 1; A and B. forming equal proportions of the aggregate at the start, and the produce be sown year after year; in twenty years the aggregate will be five of B to one of A; in fifty years there would be fifty-five of B to one of A; and in a hundred years 3,000 of B to one of A—practically a 'pure race' of B.

Needless to say the constant external conditions above postulated are never actually maintained, and therefore the conditions of different years are favourable to different races. Notwithstanding this a consideration of such purely hypothetical cases as the above leads to the conclusion that, whilst in some cases quite rapid changes in the racial character of aggregates occur, in other cases fairly uniform varieties may have arisen in course of time from mixed types.

For instance, Chevalier barley as we have it now is probably all descended from the 'few ears' (to use Chevallier's own words) from which it was originally raised in 1823. We know nothing about the ancestry of these few ears, but it seems extremely probable that the present uniformity of all the differently named Chevaliers now in cultivation is largely a consequence of natural selection. There have been from time to time many re-selections, but the progeny of these are all very much alike in racial characters. It is practically impossible to distinguish these different selections when they are growing together, and the prolonged series of Danish experiments (referred to in Chapter XI) failed to show any appreciable difference between several of them in either yield or quality of grain.

This is not, of course, to say that repeated 'pedigreeing' of a good race is not desirable. It is indeed obviously necessary if the racial character is to be maintained against the operation of all the factors which make for divergence from the original type.

It has been fairly well proved by Johannsen that maintenance of established characters is all that can be effected by

reselection within an absolutely pure race of self-fertilizing cereals, and that increased productiveness is not obtainable by selecting the most productive individuals. This is, of course, a statement in a special case of the application of the doctrine which has now been very generally accepted, that characters acquired by the individual from effects of environment only are not inherited. This doctrine as a general formula is still in dispute, but such knowledge as we have is in favour of its application in the case of self-fertilizing cereals.

Evidence in this connection is afforded by the history of Major Hallett's 'pedigree' races. In the case of his pedigree barley the most prolific plant was selected year after year for a great number of years, and formed the starting-point of a 'pure race'. The very desirable effect has been produced of maintaining absolute uniformity, and there is no evidence, so far as I am aware, that the progeny of the later selections differs from that of the earlier either in respect of the characters of the grain, or of prolificacy, or of any other racial character.

We may now briefly consider the effects likely to be produced by natural selection in the case of mixed races, 'pure races', and hybrid races of cereals respectively.

Take first the case of a mixed race introduced into and grown for several years in a particular locality and under approximately similar conditions from year to year without further admixture. One or more of the types of which the aggregate is composed will probably be better suited than the others and survive under the average conditions, and, with three out of the four of the grains sown in each year failing to reproduce grain, there may accrue a considerable difference in the character of the aggregate even within a few years, whilst after several years the aggregate may be of quite a different racial character from the original bulk. The general tendency, however, would be towards homogeneity, in consequence of some types disappearing.

Let a stock of this modified aggregate be transferred to another district with quite different soil, climatic and cultural conditions; then if there is left out of consideration for the moment the immediate effect due directly to change of

locality, the particular race or races which have best survived the previous conditions, and which make up the greater part of the aggregate, may or may not be better suited to the new conditions than some which have nearly died out. So after a few years the new conditions may remould the racial characters of the aggregate either in the direction of greater homogeneity, or at first (if only the smaller proportion of the aggregate is that best suited to the new conditions) towards greater heterogeneity. Ultimately, however, the tendency will be again towards a more or less homogeneous aggregate, differing, however, probably in general character both from the original and from the transferred aggregates. All this agrees with the observed fact that a 'change of seed' sometimes gives good results at once, sometimes after a year or two, and sometimes not at all.

Consider now the case of a 'pure race'—the progeny of an individual plant—introduced into cultivation in a particular locality. So long as this stock is kept free from admixture and neglecting 'sports', and also accidental cross-fertilization, both of which are very rare with wheat, barley and oats, the aggregate will remain homogeneous. Yield and quality will of course vary from year to year, but such crowding out of individuals as takes place will not affect the racial characters, and it is obvious that if these are constant the question whether this particular race is suited to the average conditions of a locality can comparatively soon be determined by comparison with other varieties and races in cultivation under the same external conditions.

Transferred to another environment the uniformity will be maintained, although the comparative yield and quality may be altered.

Now suppose some of this 'pure race' to be taken back and seeded in its original habitat, will the quality and yield be different from that obtained from seed of the *same* 'pure race' which has been grown there continuously?

A series of experiments bearing on this point were made by the United States Department of Agriculture many years ago, and the results were given by Dr. Le Clerc, of the Bureau of Vegetable Physiology, at Washington, in a paper to the British Association. The American results deal with the characters of the grain only. They showed that no difference

in quality was traceable to what may be called 'previous place effects'. That is to say, that a series of plots arranged side by side, seeded with grain all of the same original race, gave crops of similar quality, notwithstanding that the grain for each plot was grown the previous year in widely different localities, and was of widely different quality in consequence. The 'quality' of the grain (so far as it was due to 'place effects') was not transmitted. Only the 'racial' characters were transmitted to the crop, and these were the same with the same race wherever the grain used was grown. It would be generally agreed that this accords with the general experience that within a particular race 'quality' is determined by the immediate external conditions. I have made a series of similar experiments on a nursery scale at Warminster and my results confirm the above with regard to quality.

With regard to 'yield', however, I have consistently in three following years found with one particular 'pure race' of barley (and there seems no reason why this should not apply to any other race) significant differences in yield of grain due to the environment in which the grain which was used was grown the previous year. For instance, with the particular 'pure race' referred to (raised from a single plant in my nursery at Warminster in 1902), the resulting crop was heavier after the grain sown had been transferred to and grown on a strong clay loam, than after it had been grown on a poor chalk marl, when both were brought back to the original soil and grown alongside under precisely similar conditions. The explanation of difference in yield in one generation after a change of locality, as between two parcels of the same original race, can apparently only be put down to the fact that the grain itself brings with it something due to the soil or climate in which it was grown, which is useful to the young plant during the earlier period when it depends for nutrition on its own endosperm content. In the following year, when the progeny of both parcels of grain were resown I found no significant difference of yield, and there was of course no evidence that the racial character had been changed by the effects of environment. This instance is only of interest in this particular connection as illustrating one of the precautions necessary with reference to changes of locality when making 'variety tests' of yield. It may be

noted also, however, in passing, that effects of 'change of seed', well recognized in all ages in a vague and general way to be of great importance, call for more systematic study.[1]

It is certain that with mixed races change of locality may lead to a complete alteration of the racial character of the aggregate. On the other hand it may possibly give a result the first year after transference, consisting merely of physical differences in the grain not affecting racial character, which is probably the only result to be expected in the case of a 'pure race'.

It is doubtful at present whether we can be quite certain that any single plant selected from the progeny resulting from cross-fertilization, as the starting-point for a new race, will give us a 'pure race', which is constant in the same sense as when there has been no crossing. Even if the Mendelian hypothesis of unit characters is fully accepted, there are evidently so large a number of characters which may be genetically different, to a greater or lesser extent, in the original pair of parent plants, that some amount of 'splitting', especially in the characters which are not obvious, or which normally fluctuate widely with environment, may go on but pass unnoticed. If, however, genetic, as distinct from fluctuating, variations do take place, these will, as the result of crowding out, be either established or eliminated in the aggregate in the course of time, according as the conditions are favourable or not to the survival of the individual plants in which they occur.

On the whole it seems probable that with aggregates resulting from the progeny of hybrids there will be more risk of alteration of type through the action of natural selection, than with absolutely 'pure races' started from single individuals which have not resulted from previous crossing.

The conclusion, and this is well confirmed by general experience, is that, whatever the origin of any race of cereals, repeated artificial selection is necessary to maintain its uniformity. Purely natural selection does not, in the case of mixed races of cereals, necessarily, or indeed probably,

[1] Lisle referring to this subject said that 'the changing of all seed whatsoever is of as much use as half the dung sufficient for a crop'.—*Observations in Husbandry*, 1757, p. 83.

bring about increased rate of grain production, or even lead to a maintenance of the rate.

The plants which survive in every field of mixed races of corn are not necessarily those of the most prolific (that is, abundant seed-bearing) race. We grow our cereal crops mainly with the object of producing grain rather than straw, but the competition between crowded plants is mainly in the vegetative stage, and it is not, either with the cereals or with most other species of plants, the good seed-bearers which are inevitably the most vigorous and the most likely to survive in the vegetative stages.

A series of experiments in the barley nursery at Warminster illustrates this point.

In 1906 grains from four 'pure races' of barley grown in the nursery for several previous years were taken. Three of these races were wide-eared forms of the Goldthorpe type, and the other was one of a Danish Prentice (i.e., Archer) barley, called 'Tystofte'.

Alternate rows of each of the four races were repeated thirty times. Rows were at equal distances apart and the plants equal distances asunder, giving each plant equal soil space. Each of the rows was weighed up separately at harvest. The 'wide-eared' race which adjoined 'Tystofte' in each group gave a higher average grain produce per row by nearly 50 per cent. than 'Tystofte'. Mr. Gosset ('Student') kindly examined statistically the figures for the weights of the grain in each row, and found that the probability, taking into account the 'standard deviation' of individual rows from the mean, was enormously in favour of the 'wide-eared' being more prolific under the conditions than 'Tystofte', assuming that there was no 'interference' of the one sort prejudicial to the other. Mr. Gosset's examination of the figures for all the four races showed, however, that there was abundant evidence of 'interference', and on his suggestion in the following year these two races were grown, not in alternate rows, but in alternate plots repeated twenty times. The yield of 'Tystofte' was 10 per cent. better on the average than that of the 'wide-eared' and the odds, taking each plot separately into account, under these conditions, were very greatly in favour of 'Tystofte'.

The multiplied nursery plot experiment was repeated in

1909 with substantially the same result, and field trials also gave confirmatory results.

The explanation of the apparently contradictory result as between alternate-row and alternate-plot planting in this case is both obvious and instructive, as bearing on the operation of natural selection in cases of mixed seeding. The effect evidently was to crowd down the race which, when sown unmixed, was the most prolific. 'Tystofte' has about a week longer growing period in an average season than the 'wide-eared', but is also four to six inches shorter in the straw. There is no doubt that in this case there was crowding down of the slower growing and ripening race by the taller strawed, quicker growing (though normally less productive) race, which overtopped and shaded the other in the grain-forming stage.

There is, in fact, afforded an illustration in respect of varieties of what would be generally accepted with regard to the effect of natural selection in the case of species, viz., that in a population of mixed species of different habits it will not necessarily follow that the species which reproduces most abundantly when living apart will survive under conditions of free competition with other species.

The foregoing illustrations seem to warrant the proposition that, in order to determine an 'order of merit' of anything more than a quite temporary value as between aggregates of seed-corn, comparison must be made between at least approximately 'pure races'. Aggregates of fluctuating composition are in a state of unstable equilibrium and comparisons between them give no results of general utility.

The whole problem of mixed *versus* pure races of cereals is very much on a par with the same problem in respect of farm live stock.

Pedigree stock is best if the average external conditions of the locality are more favourable to the particular race than to others, but except under these conditions may easily be less profitable than an aggregate made up of mixed breeds.

Pedigree gives to the grower and the breeder alike the quality of the produce which they require to the extent that this is determined by racial characters. Whether or not it gives vigour of constitution and productivity depends on suitability of the 'breed' to the conditions.

In both cases, however, without 'pure races' in which the racial characters are constant, and which can therefore be systematically compared, we are groping in the dark in endeavouring to obtain better adaptation of races to different sets of average external conditions.

CHAPTER VI

FERTILIZATION

WITH most of our agricultural plants the pollen of one flowei frequently fertilizes the other flowers of the same plant, oı of another adjacent plant. Only rarely does this cross-fertilization occur with our cultivated races of barley. I barley cross-fertilized naturally as a general rule, every fielc of barley would be a mosaic of form and colour and an number of mongrel plants could be picked out quite easily.

There have been occurrences in the nursery at Warminste which could not easily have been accounted for except b assuming natural crossing to have taken place. Of cours one never sees it take place, but one assumes it has when th progeny of the grains of some plants 'split', but as mutation occur without crossing we can never make sure of it in any case

It is quite conceivable that natural crossing may be brough about in barley by insects. Thrips (a genus of minut insects of the order of Thysanoptera)[1] are often presen within the paleae before fertilization. I have no evidenc that they can carry pollen, but I know nothing about thei life-history, although I had evidence some years ago tha they fed on the turgid filaments of the anthers and wei probably responsible for the failure of the anther to develop

As an experiment, in 1928, we snipped off the upper pa of the paleae of a number of florets of a two-rowed race o several plants before the anthers had dehisced and emasc lated them by taking out the immature anthers. With ve few exceptions the ovules in all the ovaries were fertilize obviously with wind-borne pollen, because the progeny 'split We carried on cultures of the progeny until we had satisfie ourselves that actual crossing had taken place.

Natural crossing occurs no doubt sometimes with a si rowed race as ovary parent, but not very frequently in o climate.

Self-fertilization is the normal process with all cereal

[1] T. *cerealium* is a common British species.

With barley and the other cereals the stigma receives the pollen from the anthers of its own flower before these emerge from the glumes. It is to this habit of self-fertilization of individual flowers that the races originating from single plants owe the constancy of their characters and the uniformity of the individual plants which make up the aggregate.

All our cultivated two-rowed barleys normally self-fertilize without the paleae opening, frequently before the ear is out of the leaf-sheath. In some cases the paleae open just wide enough to let the spent anthers partly protrude. As far as I have observed the paleae do not open after fertilization has occurred.

It would seem as if (1) elongation of the anther filament, (2) dehiscence of the anther, and (3) opening and closing of the paleae, partly caused by, or correlated with, swelling of the lodicules, all take place almost simultaneously, although probably in the above order.

Although none of our races are constantly open-flowering it is not uncommon to see individual paleae open. If this happens it is almost certain that the ovules are unfertilized and it would seem that, the flower's pollen having failed, the spikelets were attempting to catch some wind-borne pollen and had failed again, as would almost always be the case in our climate. Probably in some climates the paleae open more freely, and if so there would, of course, be more crossing. One might even hazard the suggestion that in certain climates crossing was quite frequent, and if so, relative diversity of races may be simply due to climatic or other external conditions. Moreover, there is some slight evidence that abnormal external conditions favour mutations and that these occur spasmodically and plentifully at long intervals, as De Vries (1905) believed to be the case with *Oenothera*.

I have heard of cases where open paleae have been observed: in one instance at Rothamsted on a fully manured plot: in another case on some very rich land in Ireland: and again from time to time on the edge of plots. But, unfortunately, in none of these cases were the paleae examined to see whether the ovules had been fertilized or not. I have heard it stated that if barley is very heavily manured the paleae almost always open and I have been told that in some cases fertilized seeds have been found.

I have never seen open paleae with a fertilized seed inside and I have examined several hundreds. I think it unlikely, if they open before fertilization, that fertilization subsequently occurs, because if that were the case we should get a great deal of natural crossing, especially in an experimental cage where there are hundreds of widely different races in adjoining rows. In forty years' experience I have probably had less than six such cases, and never in established races such as Archer, Plumage-Archer, etc. After the failure of fertilization the paleae generally open, and on inspection it will be found that nine out of ten of them have ovaries of the sterile type. All barley is liable to partial sterility, i.e. some 'blind' corns in some ears. There is no such thing as absolute freedom from 'blindness'.

About thirty years ago, with the help of one of Biffen's assistants, I investigated the cause of this 'blindness'. We found two distinct causes:

1. Thrips, which enter the florets before pollination and puncture the filaments of the anther, so that no pollen is formed.[1]
2. Inherited sterility, which we only found in the earlier generations of hybrid races. (This is comparable to the sterility of the infertile side florets of all two-rowed races.)

At Warminster we are always on the look out for inherited sterility and, unless we have good evidence of it, blindness is attributed to thrips. It is possible, though unlikely, that the form of the paleae may render certain florets peculiarly liable to attack by thrips, but I have no evidence of this.

It may be that in some hybrid races the ripening of the pollen and the receptivity of the ovary do not occur simultaneously and this may be the explanation of the non-fertilized ovaries which happen to a greater or less extent in hybrid barleys.

In many species self-fertilization does not take place because the pollen is impotent in contact with the ovary of the same floret. I do not know whether this is the case in other species

[1] I have never found that 'thrip blindness' had any perceptible effect on yield.

of the *Gramineae*, but it is obviously a possibility in the case of some hybrid races of barley.

Whilst my experiments indicate that if there is access of wind-blown pollen to emasculated florets fertilization readily occurs, I doubt if with any races the paleae open before the anthers have dehisced, and if they dehisce before the paleae open, then, unless the pollen is inactive, the chances of crossing appear to be very slight.

In July 1928 we took ovaries from several florets of a single ear of 'July' barley (a six-rowed race—autumn-sown) about three days after pollination. These were placed in tubes in alcohol. Examination of the tubes showed that in tube 1 containing 9 ovaries, pollinated, the paleae of the florets were all closed; in tube 2 containing 11 ovaries, not pollinated, the paleae of the florets were all open; in tube 3 containing 1 ovary, in which pollination was doubtful, the paleae were open.

It is possible that (3) was cross-fertilized, but there was no way of proving it.

Only in very rare cases does self-fertilization fail to happen and the grain become wind-fertilized, but even then the pollen would not necessarily be of another race.

In the nursery at Warminster, where barleys from all over the world are grown contiguously year after year in single rows, the individual characters of the barleys grown have been retained, with the exception of perhaps half a dozen, over a period of more than thirty years.

more and more importance to sufficiency of lime, and this also confirms the opinion and practice of earlier times. It may be taken as well established that soils deficient in lime are never good barley soils. We know that even soils resting immediately on the Chalk may sometimes have their surface strata so completely denuded of lime as to give 'finger and toe' turnips. Such soils unless they are artificially limed are fairly certain not to yield good barley.

If an attempt were made to classify the soils of the English barley-growing districts in order of merit, taking into account quality and yield combined, they would probably fall into something like the following order:

1. Drift overlying Chalk and Tertiaries in the Eastern Counties.
2. The lighter red soils in the South-West and Midlands.
3. Tertiary and recent soils of the Thames Valley and South, including the Isle of Wight.
4. Chalky soils on the slopes of the Wolds, the Chilterns and the Downs.

Rotation of Crops

Agricultural practice with regard to the production of barley in the rotation of crops is very variable within the United Kingdom. In the greater part of England barley used frequently to be grown after roots (in many cases fed on the land), or to follow another well-manured straw crop.

In East Anglia the prevalent custom was to cart half the roots (alternate pairs of roots) off the land and to feed the remainder to sheep during the winter and early spring. This gave a good preparation for barley. The spring rainfall was usually enough to poach the land, even when the ploughs were closely following the sheepfolds, and the East Anglian farmer generally succeeded in getting a friable seed-bed some time during March. Then he usually drilled the barley and sowed clover (or clover and rye-grass) a week or two later. No artificial manures were needed. I have very rarely seen an uneven young plant of barley in East Anglia. The crop-limiting factor is, in many seasons, deficient rainfall during the vegetative period of the plant's growth. In some seasons when growth had been rapid and July rainfall too heavy

there was a good deal of 'lodging', but to-day, with the stiffer-strawed and shorter-necked races, this defect is much less frequent.

Within the last twenty years, or more, there has been much less barley grown after sheepfold and I think that now the custom has almost gone out of use.

The Norfolk four-course rotation—roots, barley, clover, wheat—is the best-known rotation and is no doubt a wonderful device for putting nitrogen into the soil. It is said to have originated in Hertfordshire, but it was Thomas Coke of Norfolk who first introduced it on his great estate in N.W. Norfolk, where he reclaimed thousands of acres from waste and by his efforts and example added very substantially to the annual value of Norfolk agricultural produce, as well as contributing very handsomely to the comfort and welfare of the agricultural community.

The necessity of the inclusion of barley in the rotation is largely governed by the need of a spring-grown crop, and its suitability for this depends in turn on the district and soil.

A crop rotation can be less, or more, than four years, and I believe that both a six- and eight-course rotation is now practised on many farms as being more economical to the farmer than the four-course rotation. These extended rotations are said to produce a very high proportion of cash crops, five-sixths of the acreage, in some cases, being turned into cash straight away. This is obviously an advantage in the eastern counties of England, where barley is relied upon to provide for rent and wages.

Within the last ten years, or more, barley has been grown to an increasing extent after sugar-beet and after clover-ley. I think, however, that about the same proportion of barley is grown after wheat as formerly, although in the south-west of England there is a relatively much reduced acreage where barley after wheat was the regular practice.

I have found that barley after roots gives a higher yield than after corn, but that when it follows a corn crop it stands up better than when following roots or sugar-beet. Barley following sugar-beet gives higher yields than barley following corn, but I think perhaps it gives slightly lower quality.

In 1914 over a considerable area in East Norfolk barley was harvested loose, but more recently the reaper-binder has been universally used.

There were defects in all these machines, but each was an improvement on the other in some respects. The principal defect of the binder is that it ties the sheaves tight and it is difficult to get the inside of the sheaves dry after much rain has fallen upon them. There has been for some time a prejudice against tying barley into sheaves and it is a matter of common observation that since the use of this implement much more barley is 'mowburnt' because it is not open to the sun and wind. There is no doubt that in many seasons barley cut, whether with the scythe or with the mower, and left loose in swath for a day or two (three or four days was customary) does dry, take colour and mellow more than if tied into sheaves. In some seasons (perhaps one in four) the reaper-binder leads to trouble. For instance: if cutting has been delayed by adverse weather after the crop is ripe, the clover makes headway and then the cutting of the barley must be further delayed until the clover is fairly dry, or there is a risk of heating in the stack. In some seasons, if there is a lot of clover, which is always green when the barley is cut and tied, the farmer has to choose between 'cutting the bonds' or waiting for another week of fine weather in which to dry the sheaves. Perhaps with the use of the still more modern implement, the drier, this contingency will not arise.

In 1930 a still more portentous implement, the 'combine harvester', appeared for the first time in England. This machine, brought over from America, cuts and threshes the barley and throws out the grain in bags, all in one operation, as it travels round and round the field, drawn by a tractor. There is no sheaf binding.

No doubt the use of this machine saves a considerable amount of grain. When one walks over fields that have been harvested by this method one sees far fewer ears lying on the ground than in fields where the binder has been used. The tying up of the sheaves must inevitably lead to a certain wastage. Also the grain is not put into stack and consequently rats and mice do not get at it. The amount of grain eaten in this country by these pests has been variously estimated by statisticians, but we know that it is

a very large quantity. I think it is probable that the combine harvester, one way and another, saves quite 5 per cent. of the total grain, and probably more. A further advantage of combine harvesting is that less time is wasted in 'catchy' weather, when it is fine one day and wet the next; it enables the farmer to get on with his work more quickly.

Of course the combine and the drier together require skilled labour, but the agricultural worker, taking him all round, is as skilled a worker as any man who is employed in any other form of manual labour. Kipling describes him as: 'Bailiff, Woodman, Wheelwright, Field Surveyor, Engineer'. What more can we ask of him?

I suppose that about 5 per cent. of the barley of the country to-day is harvested by the combine harvester. The farmer who buys one of these machines for about £500 has generally also to invest in a drier, because since there is no drying of the grain by sun and air after cutting, and no sweating in the stack, the grain is often not dry enough to be safe in sack for more than a few weeks and in consequence is not saleable for malting.

I have seen several combines and driers in operation and I have no doubt that they make much better work in good and in bad weather than the old binders—provided the combination of cutting and drying is effectively done.

The future development of combine harvesting will of course depend upon the amount of spare capital available for investment in agriculture. It will not be of much help to a farmer who farms, say, 400 to 500 acres and who is working up to the limit of his capital. But it is possible that smaller and handier types of combine harvesters may appear before long.

I imagine that mechanized agriculture, if we take into account tractor ploughing with the maintenance of a few horses and getting nearly all the work on the farm done by machinery, involves the use of about 50 per cent. more capital on any farm, and it obviously requires more capital than can be employed on comparatively small farms. It is therefore not likely that combine harvesting will flood the markets with grain at a particular time of the year for some time yet. It is, however, a step in the right direction and will enable us to stand up better to foreign competition.

CHAPTER IX

INFLUENCE OF CLIMATE AND SEASON ON AVERAGE YIELD AND QUALITY OF BARLEY IN ENGLAND

THERE is great variability in temperature and rainfall in different parts of England and it is interesting to note the relation between average temperature and rainfall in various districts on the one hand, and on the other hand, the average yield and quality of barley produced in the same districts. For this purpose attention may be confined to the larger barley-growing districts, and to a few typical counties.

TABLE IV

Barley Districts	1st q'rter	2nd q'rter	3rd q'rter	4th q'rter	Yearly average	Avg. yield, 10-year period 1896–1905 [1] (bushels)	Avg. yield, 10-year period 1929–38 [2] (bushels)
				Mean Annual Temperatures			
N. Eastern .	38·9	50·1	57·6	43·7	47·3	35·1	35·1
Eastern .	38·8	51·0	59·0	43·1	48·0	34·3	33·9
S. Eastern .	40·5	53·0	60·6	45·0	49·7	32·7	31·0
S. Western .	43·4	53·2	59·9	47·6	51·0	31·3	34·1
Kent . .	39·2	51·6	59·8	44·2	48·8	37·9	39·3
N'th'mb'land	39·1	48·9	56·5	43·0	46·9	35·8	34·5
Cornwall .	44·0	53·2	60·0	47·9	51·3	32·0	35·3
Hunts . .	39·2	52·5	60·1	43·0	48·8	30·1	29·5
				Average Inches of Rain			
N. Eastern .	5·19	5·55	7·67	7·7	26·1	35·1	35·1
Eastern .	5·35	5·44	7·68	8·0	26·5	34·3	33·9
S. Eastern .	6·17	5·45	7·34	8·5	27·5	32·7	31·0
S. Western .	10·73	7·08	9·85	13·9	41·5	31·3	34·1
Kent . .	6·42	5·28	7·68	9·96	29·3	37·9	39·3
N'th'mb'land	5·84	5·60	8·10	8·53	28·1	35·8	34·5
Cornwall .	11·43	7·24	9·79	15·24	43·7	32·0	35·3
Hunts . .	4·72	5·46	7·05	6·72	23·9	30·1	29·5

[1] *Agrl. Statistics, Board of Agriculture and Fisheries*, 1906, vol. xli, Part II.
[2] The figures in this column were kindly supplied by the Ministry of Agriculture and Fisheries. They are obtained by applying to the relative published figures (*Agrl. Statistics, Min. Agr. and Fisheries*, 1939, vol. lxxix, Part I) a conversion factor of 54·2 lbs. to the bushel.

The averages taken over the largest areas seem to show that the highest yields are in the driest and coldest districts and *vice versa*, but there are exceptional areas within the largest districts. Kent, with an estimated yield higher than any other county in England, is one exception. Huntingdon, on the other hand, the driest county in England, has a much under-average yield: lower than Cornwall, which is almost the wettest.

Averages are apt to be misleading, but when we take a large area there is a probability that any errors may to some extent balance each other.

Mr. W. N. Shaw [1] in the *Journal of the Royal Statistical Society* (1905) gave a very full record of the relation between weather and crops for twenty years, 1885–1904. He showed that there was a very close coincidence between low autumn rainfall and high yields of wheat in the following season, and it might appear probable that there would be a corresponding coincidence between high average yield of barley and low rainfall in the first three months of the year. I have very slight evidence of such relation. In only seven years out of the twenty cited were excessive autumn and winter rainfall followed by under-average barley crops, or *vice versa.*

In regard to the spring rainfall there were thirteen years out of twenty when either a dry spring was followed by an over-average crop or a wet spring by an under-average crop. In the other seven years there was the opposite relation.

Nor is there any definite relation between summer rainfall and average crops. In eleven years out of the twenty the evidence is in one direction and in the remaining nine in the other.

Taking the two worst years for yield since 1884 in Mr. Shaw's period, viz., 1893 and 1904, in both years excess of rain in the previous autumn and winter was followed by dry springs and summers. In one of the best years for yield (1885) a wet winter and spring rainfall was followed by a very dry summer. In 1890, the second-best year of the period for yield, these conditions were reversed.

With regard to quality, as we come South down to the East coast, whilst the yield declines it will be generally agreed that the average quality of the barley improves. Barley

[1] Formerly head of the Royal Meteorological Office—later Sir Napier Shaw, F.R.S.

gains in quality if not in yield in England with rise of mean yearly temperature. There is no great difference in rainfall as between the North-East and the South-East, and indeed probably both yield and quality of barley on the East coast generally suffer as much in a series of years from deficiency as from excess of rainfall, and perhaps more especially from deficient rainfall during the latter part of the growing period.

In the North-East and Eastern districts, where the yields are higher than in the South-East and in the South-West, there is less rain all through the year than in the South-West and less in the first quarter of the year than in the second; whereas in the South-East, and much more in the South-West, there is the reverse condition. The average winter rainfall in some parts of the South-West is so heavy that sowing is often unduly retarded. Here, however, the warning to beware of averages is especially required. These figures for rainfall are made up by averaging the returns of a great number of stations, and in a hilly country like the South-West the rainfall varies greatly even within a few miles. If the total rainfall, for instance, on Dartmoor, Exmoor, the Quantocks and the Mendip districts, where no barley is grown on the higher land, were excluded, the South-West would show a perceptibly lower average, and these differences do not occur to anything like the same extent in the more level Eastern districts.

The county of Somerset grows on an average of seasons as good a quality barley as any in England, notwithstanding its higher rainfall, with yield above the average of the Southern counties. It seems probable that the higher temperatures here count far more in favour of the plant than the rainfall tells against it. Winter and spring temperatures are perceptibly higher than in the Eastern counties, and the seed goes into a warmer bed.

The rainfall and temperature figures for the South-West include Cornwall, and similarly those for the South-East include Kent. Neither of these counties is a typical barley-growing county, but a comparison between them is instructive. In the period we are dealing with both of them grew about 30,000 acres of barley, a small quantity compared with the Eastern counties, but more than is grown in the majority of other counties.

Cornwall grows an under-average yield of barley, and generally of poor quality. Kent, on the other hand, shows the highest average yield in our period of any county in England, with much over-average quality. Cornwall has a very excessive rainfall, especially in winter—far higher than any other county growing any considerable acreage of barley. Kent has a low rainfall. Cornwall has considerably higher winter temperature than any other county in the United Kingdom, but between midwinter and midsummer the area of highest temperature shifts from the extreme South-West towards the South-East, and the average summer temperature of the barley district in Kent is just about the same as the summer temperature in Cornwall. Looking to the fact that there is no general relation between winter rainfall over the whole country and the produce of barley in different seasons, and to the fact that the chief climatic difference between Cornwall and Kent is the winter rainfall, we may safely say that the great difference between the yield and quality of barley in Cornwall and Kent respectively is more a question of soil and cultivation than climate. There is no glacial drift in Cornwall, and the soil consists mainly of broken-down residues of primary rocks. In Kent barley is grown mainly on Chalk, Greensand, and Tertiary sands and gravels.

Now by way of another contrast let us compare the Kent barley district with that of the extreme North of England. Northumberland and Kent, in the period we are dealing with, had about the same acreage of barley land. Both grew over-average yields, much above that of England generally. The average temperature is of course substantially lower in the North-East. The average rainfall is about the same in the two districts. The quality of the Northern barley is inferior to that of Kent. The barley-growing districts of Northumberland are on glacial drift. It seems fairly certain that the difference in quality in favour of the South-East is mainly due to the perceptibly higher average temperature, leading to earlier sowing and brighter maturing conditions. The over-average yield with good quality in Kent, as in Somerset, may safely be set down to the combination of relatively high temperature and good barley soils.

Although we are dealing with English barley we might just mention the conditions (1) in the Lothians; and (2) in Ireland.

In both cases there are substantially higher average yields than in any part of England. The average yield in Midlothian from 1896 to 1905 was calculated as 44 bushels per acre, against 34 bushels for the same period in the East of England. The average yield in Ireland over the same period was about 40 bushels. Rainfall in the Lothians is about the same as in the East of England, and in Ireland about the same as the South-West of England. Quality in average years was probably not so good in the Lothians as in the Eastern counties of England for that period, and quality in Ireland was probably inferior over the same period.

The indications in both cases point to soil conditions and cultivation as the main controlling factors determining the much higher average yield. This is certainly true as regards the Lothians. In Ireland the barley districts are small and scattered, but they comprise some of the best soils in the island. The climate is warm and moist, with absence of late night frosts.

As with soil conditions, so with climate and season, the effects on the yield and quality of barley are so complex as almost to defy an attempt at a summary.

The arable districts on the East side of England are the driest and coldest. They give on an average higher yields of barley than the warmer and moister districts in England, where there is a much lower proportion of arable as compared with grass land. On the other hand, the higher temperatures, and even, in not a few seasons, the higher rainfall of the South and South-West are favourable to quality. As to seasons, deficient yield is as often due to drought as to excessive rainfall.

It is hardly to be expected that any relation would be traceable between yearly, or even quarterly, rainfall and quality of barley as between different districts, seeing that it is the weather, and by no means the rainfall only, of the two critical months before and during harvest which, more than all other conditions combined, determines quality. But admitting this, there are fairly definite characters attaching to the barleys of different districts year after year, combined with fairly constant differences in yield, and the conclusion is that over a series of years it is as much, or more, the character of the soil as of the climate which is the determining factor.

Average yields per acre over a long series of years up to 1905 were approximately as follows: England, 32 bushels; Scotland, 36 bushels; Ireland, 40 bushels. Average yields over a period of ten years, 1929–38, were: England, 33·4 bushels; Scotland, 39·3 bushels; N. Ireland, 44·1 bushels; Eire, 44·8 bushels; all Ireland, 44·8 bushels.[1]

As between different races under equal conditions, there is an average range of about 4 to 6 bushels. We might safely define an over-average barley land as that which gives yields in average seasons under fair conditions of cultivation between 38 and 48 bushels per acre of grain, with an average nitrogen content of less than 1·6 per cent. of the dry matter.

Average yields over a series of years of more than 48 bushels with an average nitrogen content of under 1·6 per cent. point to exceptionally favourable all-round situation and condition. These are met with in the Lothians, but in no other considerable district of the United Kingdom.

The water content of the grain depends mainly on harvesting conditions and sweating in stack, but on an average of years it will probably be 2 or 3 per cent. less with the more favourable harvesting conditions in the East and South than in the North and West of England.

[1] Figures for the ten-year period were kindly supplied by the Ministry of Agriculture: the figures for Ireland are calculated on a basis of 50 lbs. per bushel.

CHAPTER X

ACREAGE, DISTRIBUTION AND YIELD OF BARLEY: (1) IN ENGLAND AND WALES; AND (2) IN GREAT BRITAIN

(1)

NOTEWORTHY changes have occurred not only in the total acreage of barley in England and Wales, but also in its distribution. The very condensed table given below, with approximate figures, has been compiled from official statistics [1]:

TABLE V.—Acreage of Barley in England and Wales

10-year periods	Average barley acreage	Per cent. of 1886–95
	Million	
1886–95	1·9	100
1896–05	1·7	90
1906–15	1·5	79
1916–25	1·4	74
1926–35	1·0	53
4-year period 1936–39	0·86	45

Up to the middle of the period the barley acreage decreased by over 20 per cent. and continued to decrease. Whilst the area under crops decreased in the aggregate in 1939, the area under barley in that year, viz., 910,075 acres, was the highest recorded since 1932.

During the last forty to forty-five years of the period shown in the above table there has been a very marked change in the distribution of the reduced English acreage. This has been best maintained in the Eastern counties with their lower rainfall.

The following table gives the barley acreages in England (only) and in some groups of counties in 1894, 1934 and 1939:

[1] 'Agricultural Statistics' of the Ministry of Agriculture.

TABLE VI.—Distribution of Barley in England

	1894 Acres	1934 Acres	1939 Acres	1934 % of 1894	1939 % of 1894	1939 % of 1934
England . . .	1,786,142	832,309	888,154	47	50	107
East Coast						
Yorks (N. Riding) .	74,030	44,938	48,315	62	65	108
Yorks (E. Riding) .	69,084	51,142	56,699	74	82	111
Lincolnshire . .	132,796	111,110	109,889	84	83	99
Norfolk . . .	211,033	163,193	184,719	77	87	113
Suffolk . . .	146,392	103,674	119,987	71	82	115
Essex	102,920	62,340	63,888	61	62	102
Kent	43,112	15,750	16,184	36	37	103
Totals:	779,367	552,147	599,681	71	77	109
Totals % of England .	44·1	66·4	67·5			
South-West Counties						
Cornwall . . .	35,642	6,965	8,143	20	23	117
Devon . . .	53,452	16,473	21,273	31	40	130
Dorset . . .	31,196	8,622	8,430	28	27	98
Somerset . . .	29,643	9,904	11,215	34	38	113
Wilts	47,615	11,254	12,732	24	27	113
Hants (including Isle of Wight) . . .	45,758	19,399	23,160	42	51	120
Berks	30,499	10,635	12,488	35	41	117
Totals:	273,805	83,252	97,441	30	36	117
Totals % of England .	15·4	10·0	11·0			
Some Midland Counties						
Stafford . . .	16,867	1,632	1,698	10	10	104
Derby. . . .	7,006	1,226	1,118	17	16	91
Notts	36,881	9,022	8,636	25	23	96
Leicester . . .	15,976	2,676	2,625	16	16	98
Warwick . . .	16,022	2,414	1,948	15	12	81
Worcester . . .	10,960	876	929	8	8	106
Totals:	103,712	17,846	16,954	17	16	95
Totals % of England .	5·9	2·1	1·9			
Yorks (W. Riding) .	56,455	14,910	15,149	26	27	102
Yorks (W. Riding) % of England . . .	3·2	1·8	1·7			
All other counties .	553,803	164,154	158,929	30	29	97
All other counties % of England . . .	31·0	19·7	17·9			

The figures show that in 1934 Lincolnshire and Norfolk were the two areas which best maintained their old acreage. In 1939 there was an increased acreage in every Eastern county compared with 1934, with the exception of

Lincolnshire. Norfolk and Suffolk showed the greatest increased acreage.[1]

There were heavy decreases in all the South-West counties in 1934 compared with the old acreage. In 1939 every South-West county showed an increase on the 1934 acreage, except Dorest.

In the Midland counties there was a heavy decreased acreage in 1934 compared with 1894. In 1939 the figures show a still further decreased acreage, with the exception of Stafford and Worcester.

Yorks (W. Riding) showed a considerable decrease in 1934 compared with the old acreage, and a small increase in 1939 on the 1934 acreage.

To give any, even plausible, reasons for these 'differential' responses of barley acreages to altered conditions is difficult. We may be sure, however, that the conditions which have operated have been very diverse. In some counties, e.g. Worcestershire, fruit and vegetables (even asparagus) have been partly responsible. In Wiltshire the United Dairies has much to its credit. That company has been very ably directed from this county and I believe the increase in milk production has been as high as in any other English county.

The thousand-acre farm on the edge of Salisbury Plain where I was brought up, and which grew about 100 acres of barley annually in the seventies of last century, is now (1939) the property of the War Office and is all grass.

Up to the beginning of the war (1939) English farm land, for a great number of years, in four out of five counties had been 'going down to grass'. Some authorities in high places and with wide vision of what from the national point of view is most to be desired, notably Sir R. G. Stapledon (1935), believed that it would be a good thing for the country and, incidentally, ensure our greater safety, if half the grass land, including all the poor grass land, were ploughed up and the remainder of it so farmed with the aid of drying plants for young grass as to yield twice as much as heretofore per acre of nutriment for animals and for our milk supply.[2]

[1] In 1938 the county of Norfolk grew about one-fifth of the barley grown in England and was in a position to provide about one-third of the total home-grown barley of malting quality.

[2] In 1866 there were 14·2 million acres of arable land in England and Wales: in 1938 there were 9·0 million acres arable and 14·0 million acres pasture.

Barley yields have been estimated since 1886 for the Ministry of Agriculture by local representatives and summarized in the published returns.

Taking five ten-year periods and one four-year period we get the following figures for England and Wales:

TABLE VII.—Average Yields of Barley in England and Wales

Years	Cwts. per acre	Percentage of period 1886–95
1886–95	15·5	100
1896–05	15·5	100
1906–15 [1]	15·8	102
1916–25 [1]	14·6	94
1926–35	16·3	105
1936–39 [2]	16·4	106

In the ten-year period 1929–38 the average yield in England and Wales was 16·2 cwts., and for the years 1938 and 1939, 18·1 and 17·5 cwts. respectively. Variation of the average in different years is about 15 to 18 cwts.

If instead of taking the average yields of the whole country we extract the figures for the Holland division of Lincolnshire very convincing figures are shown for the improvement in the yield of barley. This division has a small acreage but a very high average yield.

Five years' averages are given overleaf for Lincolnshire and for the Holland division only. The latter figures show a really steady increment from the end of the 1914–18 war.

[1] These periods include the war years 1914–18.

[2] In this period the highest average yield for England and Wales was in 1938, viz., 18·1 cwts.—an exceptional yield. The lowest average yield in this period was in 1937, viz., 14·5 cwts. (The harvest of 1937 was exceptionally bad.)

[TABLE.

Five-year period:	Average yields per acre (cwts.)	
1893–1897	15·5	Lincolnshire.
1898–1902	14·9	
1903–1907	15·2	
1905–1912	15·1	
1913–1917	16·3	Holland division only.
1918–1922	17·2	
1922–1927	19·2	
1928–1932	19·9	
1933–1937	21·2	
Ten-year period:		
1885–1894	15·5	Lincolnshire (including Holland).[1]

[1] Holland was not distinguished until 1913.

(2)

In Great Britain the acreage of the cereal crops, viz., wheat, barley and oats, is determined by differential conditions of soil and climate over wide areas. On the whole arable area, and on every arable field, one or other of the three cereals can be grown, but in most districts and on most farms one or other is not only the most profitable to the farmer but also yields more human nutriment.

The average barley acreage in Great Britain for the ten-year period 1930–39 was 0·97 million. The acreage in 1938 was 984,427 acres and in 1939, 1,009,670 acres.

In 1939 wheat represented 70 per cent. of the cereal area in Huntingdonshire and only 0·1 per cent. in Aberdeen; barley was 50 per cent. of the cereal area in Norfolk and only 0·6 per cent. in Cumberland; oats were 93·9 per cent. of the cereal area in Aberdeen and only 15 per cent. in Norfolk.

The arable farmer in Great Britain depends to a very great extent for his profits on the sale of wheat and barley. Except in seasons when these crops have been badly damaged by adverse conditions, probably 80 per cent. of the total growth of these two cereals passes out of the farmers' hands. About 8 to 10 per cent. of the wheat and barley grown in any year is used for seeding the following year and probably about 10 per cent. of it (usually the inferior and damaged grain) is used for feeding to animals. In Wales and in the South-West

of England there are, however, considerable areas where nearly all the barley grown is used for feeding purposes. Oats are to a very large extent consumed on the farms on which they are grown and probably not more than 30 per cent. of the total crop of Great Britain is sold by the growers. On this account there is a tendency for oats to be more generally grown than wheat or barley in mixed arable and pasture districts. Moreover, the climatic conditions which are favourable to grass are generally also more favourable to oats than to the other cereals.

With few exceptions there is a proportionately larger area of barley in the drier counties, in which there is also a higher proportion of arable land, and there is a comparatively small area of barley as compared with oats in the wetter pasture districts. Barley having a somewhat shorter growing period than wheat or oats under the same climatic conditions can be more profitably grown in some areas where not only is the average annual rainfall limited, but also generally limited to a special season.

Before 1922 there was a slight tendency for yields of barley in Great Britain to fall, namely, at the average rate of 0·1 cwt. per acre. Since 1922 there has been a steadily progressive increase at about the rate of 0·5 cwt. per annum. The average yield per acre of barley in Great Britain for the ten-year period 1920–29 was 15·8 cwts. and for the ten-year period 1930–39, 16·4 cwts., an increase of nearly 4 per cent.

Owing to the outbreak of war, in 1939, a 'ploughing-up' policy became necessary in order to maintain the food supply of the country, with the result that the acreage under barley to-day is greater than it has been for a number of years and will no doubt continue to increase to the utmost limit. Indeed, it is to be hoped that in future a much larger percentage of our population will live on the land and I hope the day may come when the acreage of barley in England, at any rate, may be increased by an average of at least 50 per cent. of that of the pre-war periods.

CHAPTER XI

OLD ESTABLISHED VARIETIES AND RACES OF BARLEY GROWN IN GREAT BRITAIN

GOING from North to South and omitting barleys grown mainly for feeding purposes, the races generally grown in Great Britain up to about 1914 were as follows:

In the north-eastern counties of Scotland, Scotch Common was generally grown. This variety is composed of a large number of mixed races. There were, however, some selected races of Scotch Common in cultivation, one of which, known as 'St. Medoes', originated in the parish of that name in the Carse of Gowrie.

The ear of Scotch Common is narrow, the grain is generally rather small and the colour and quality uneven, partly on account of the mixture of race which is prevalent and partly because of the unfavourable climatic conditions of many parts of the district. It was, however, suited to the districts in which it was grown in respect of its hardy character and from the fact that it has a relatively short growing period, consequently ripening earlier than other sorts.

In Fife, the Lothians, the Berwick district, Northumberland, Yorkshire and N. Lincolnshire the barley grown was generally of the wide-eared or Goldthorpe type, so called from a 'pure race' raised by Mr. Dyson of Goldthorpe, Yorkshire, from a single ear, shaped like Spratt, which he discovered in 1889 in a field of Chevalier barley. This ear had grain of larger size and better colour, and it soon gave rise to a new sort which is quite readily distinguishable from Spratt, though of the same general shape and habit. Whether Mr. Dyson's single ear was a 'sport', or whether it was seeded accidentally by a grain present of the older Spratt barley, we do not know. There is no doubt, however, that it has grown true to type since its introduction.

The record of this barley is remarkably instructive, for it shows incontestably that the progeny of a single plant may

have quite well-marked characters differentiating it clearly from other stocks.

There were also in general cultivation several well-known hybrid barleys of the wide-eared class. It is a general characteristic of the wide-eared barleys that the grain is larger than that of the narrow-eared sorts. On this account they yield on an average more extract to the brewer and are preferred by most maltsters in Scotland and in the North of England. True Chevalier barleys were grown to some extent in Scotland, but the term 'Chevalier' is commonly used in some parts of Scotland for all races other than Scotch Common.

Wide-eared barleys were also the prevalent type in Shropshire, in many districts of the Midlands, in the Fen District, and in some parts of Essex. An old English wide-eared variety called Spratt, which is inferior in quality and colour to Goldthorpe, but with a very stiff straw, was formerly grown in a few scattered districts in the Fens and in Essex up to about 1920, but it has been generally replaced by the newer breeds of wide-eared barleys. It was a heavy cropper on certain rich soils and usually produced a large quantity of straw, which with weaker-strawed sorts would certainly have caused 'lodging'. It is wider in the ear than Goldthorpe and long-necked (as are most wide-eared barleys), and when fully ripe liable to be brittle both in the ear and in the neck. The appearance of the grain is generally distinct in the wide-eared sorts, and whilst few experts could be sure on inspection to what particular 'sort' a barley of Chevalier type belonged, the Goldthorpes are generally readily distinguishable from Chevaliers even after threshing. Goldthorpe and the other wide-eared barleys have thick stems and short 'knots', and although the last internode is long, the head does not fall over as much as with the Archers and Chevaliers. There is, however, a tendency for the straw to become 'kinked' and this is more serious than being 'knee-bent'. With neck-bent barley of the wide-eared type there is loss from breaking.

Wide-eared barleys show a greater tendency to deteriorate than narrow-eared, but their special merit is that their straw is generally stouter than that of the narrow-eared varieties, so that they are generally able to stand up under conditions which would cause the latter to 'lodge'.

In England generally, the three best-known types of barley cultivated in the earlier years, which can be recognized as distinct by their general appearance, were Chevaliers and Archers, both narrow-eared; and Spratt (wide-eared). Of course there are many strains of these, but they all more or less resemble one of the types, or are crosses between them. From our leading agricultural seedsmen we get barley so free from admixture and so generally uniform as to make it fairly certain that the grain has been in many cases grown up from single selected plants of one or more of these types, and in some cases we have definite records of this having been done. The evenness in the character of the plant and of the grain produced from seed so grown up is very noticeable, and, needless to say, the uniformity of sample so obtained is a very valuable quality. We find, however, that even without any artificial selection of this kind there have been, and there still are, 'sorts' of barley more or less uniform which must owe their uniformity to other causes.

There are a few old records which are interesting in this connection and perhaps that of Edward Lisle given in his *Observations* is the most instructive. He made many journeys from his home, Crux Easton, in Hampshire, to the Isle of Wight, Dorsetshire, Wiltshire and Leicestershire. He describes with much detail his discussions with various farmers and maltsters whom he met on these journeys as to the various kinds of barley grown in the districts. His observations are all the more interesting because he evidently judged the grain in respect of quality just about as we do to-day. He says:

'It is agreed, that is the best sort of barley, that is not blackish at the tail, nor has a deep redness, but is of a pale lively yellow colour, with a bright whitishness in it, and if the rind is a little curdled, so much the better.

'It is said, that the curdled-rinded barley is the finer sort, and has the thinner coat.—Being in the barn, and handling both the smooth-coated barley and the curdle-coated, I perceived the reason thereof; for if barley comes to sweat in the mow, and to dry, if it be thin-coated, it will curdle, but the rind of thick-coated barley, being stiff, will not shrink, but will lie smooth and hollow, tho' the inside flour shrinks from it' (p. 155).

Rath Ripe barley, or early ripe barley, was regularly grown in certain districts where it had a reputation, and seed from these districts was frequently transported to others. Lisle tried it over and over again, but was strongly against it for the poor and cold lands of the North Hampshire Downs, where he farmed. Neither on his clay land nor on his white land did it give good results. To quote his own words:

'I sowed this year (1707) rath-ripe barley in very poor white ground; I also sowed the same in very good strong clay-land: no rain fell to bring it up till June, and after that we had frequent showers, and plenty of rain till harvest, and in harvest, and yet I observed my rath-ripe barley in the poor light land miserably bent, broken in the straw, and harled or fallen down: in the strong clay-land it did the same, but not so much, tho' the straw and the leaf of the straw was blighted, and full of black specks, the ear thin, and its colour lost in all the rath-ripe barley, whereas the straw of the late-ripe barley was both free from these spots and stood upright with good strength.—I do infer from hence, that, seeing the clay-land in our hill-country, tho' in good heart, and the moistest ground we have, and in a moist year too, cannot sufficiently feed the straw of the rath-ripe barley, so as to enable it to stand upright, but suffers it to be languid and withering; I say, from hence I infer, that rath-ripe barley cannot be a proper sort of barley for us to sow; because in our hill-country, where the straw breaks or starves three or four weeks before harvest, it must needs be a thin coarse grain; therefore in our hill-country it is best to sow late-ripe barley, tho' we should provide three or four horses extraordinary against sowing time, in order to get the corn into the ground a week before May begins' (p. 148).

Middle-Ripe barley he tried a few times, but concluded that it had very much the same defects as rath-ripe, but to a lesser degree.

Late-Ripe barley evidently suited all his land the best, and he goes into a long explanation of its merits, of which the chief are that it is much stronger in the straw, holds out well and is more even at harvest. He considers the straw also to be better value for feeding than that of the earlier sorts. He makes a comparison between rath- and late-ripe barley in the following words:

'It does not seem very easy to make a conjecture of the nature of late-ripe and rath-ripe barley, and to give reasons why the late-ripe agrees best with cold, and the early-ripe with hot grounds, and with a hotter climate; but I shall venture, however, to deliver my notion of the matter. I conceive the reason why one sort of grain is late-ripe, another rath- or early-ripe is from the stamina and constituent parts of each grain, which in the rath-ripe sort are of a looser and opener texture in the fistular parts and glands. The rath-ripe barley having finished its course, and come to a maturity in less time by being committed to a warm bed, shows the vessels of the seed to be less compact, and the fibres and ligatures not so well strung, and their tones looser than those of the late-ripe; for the quicker the growth of the solids are, in animals as well as plants, the parts which contribute towards such growth and increase are less solid and compact, as carrying with them a greater mixture of fluids, which are the necessary medium for consolidating the harder or drier particles, which united make the solids, and therefore, the cement being of a looser substance, no wonder if the fibres of such seeds are so too: thus the parts of the rath-ripe seeds are not corded, braced, or faggotted together with so strong an union or texture as the late-ripe seeds, which last being sowed in cold ground, and in a cold clime, the vegetable juices are sent up in less plenty, and the particles that contribute to the solids are not over-flowed with so liberal a quantity of fluids, which are therefore the firmer matured and digested' (p. 150).

[*This is not scientific language according to our ideas, but I fancy that Lisle meant just about the same as we do when we say that quick-growing varieties of plants will contain a relatively lower proportion of elaborated material to protoplasm than will slower-growing plants of the same species.*]

Spratt barley Lisle describes just as we should to-day, and he considers it specially suitable for rich land. He does not apparently grow it himself, but recommends it to a friend in Bedfordshire, who takes him to see some newly broken-up pasture which, even after two corn crops, is still too strong for ordinary barley.

'Mr. Clerk of Leicestershire informed me, that sprat or battle-door barley required a strong good land, that its

peculiar property was, that it would not run up to a length of straw, tho' in good land, so as to lodge, as other barley would, and that it had a stronger and more pithy straw, but not so good for fodder.

'Mr. Ray, fo. 1243, speaking of battle-door or sprat barley, says, it is thought to be more safe than other barley from the depredations of birds, because its grains are more difficult to be torn from the ear than the grains of other barley'.

. . . .

'Mr. Johnson of Bedfordshire, of whose judgment I have a great opinion, after he had sown great-wheat in a new broken-up very rich pasture-ground (which sort of wheat he chose, because it was the least subject of any to lodge) and the next year had sown beans, the year following, being the third year of sowing the ground, took me with him to view it, in order to advise with me what grain he should sow: he thought it would be too rank for barley, because that is more apt to lodge than oats, and also too rank for oats, and was therefore inclinable either to sow great-wheat and red-straw-wheat mixed, that the former might help to support the latter from lodging and falling, it being a rank ground, or else to sow red-straw-wheat alone, because next to great-wheat that supported itself the best.—I have known great-wheat and red-straw-wheat often sowed in the north, in good land, for the same reason. I agreed with his reasons, as being good, but told him, I should rather recommend battle-door or sprat-barley, if he would send it from beyond London, it being not only a shorter, but also a stronger strawed barley than any in the north, and therefore fitter to sow on rich land, in order to prevent lodging, and was also good to mix with other barley, to help to support it' (pp. 151–152).

Can we identify these old sorts of barley as represented amongst those that we know of? I think that the old rath-ripe barley has practically gone out of cultivation in England. There was in Ireland a good deal of unselected barley known as 'Old Irish' which corresponds to it, judging from Lisle's description, and on the Continent a similar strain (probably selected) is known as 'Hanna'. Neither of these sorts is now profitable to the grower. Their only recommendation is early ripening.

Possibly Lisle's middle-ripe barley is represented by

Chevalier, but more probably it was a mixture of late and early barley.

There is not much doubt that the old late-ripe barley is represented by what we know as 'Archer' barley and is probably the old common English narrow-eared barley of the country. It has all the characters which Lisle describes. Apparently the late and early ripening habit in those days was more or less maintained by getting seed periodically from districts in which these sorts had originated and where they generally maintained these characters.

The origin of Chevalier barley is rather doubtful. As we know it, it is the progeny of a few ears found in the garden of one Andrews, a labourer employed by the Rev. J. B. Chevallier. It was selected and re-selected, probably from single plants, by himself, and certainly later by many seed-corn growers. It is fairly certain that before 1886, 80 to 90 per cent. of the barley grown in England was the progeny of one plant of this race. It is not on record that the reverend gentleman himself made a profit from his barley; however that may be, it is certain that no race of any species of any farm plant before or since spread so extensively as this. The barley was well and truly called 'Chevalier' (vide *Oxford Dictionary*).

I received from Mr. J. B. Chevallier, of Aspall Hall, Suffolk, copy of a letter written by his grandfather which brings to light what is probably the true story of the origin of this barley. It reads:

'A labourer (named John Andrews) living in a cottage of mine at Debenham, in this County, as he passed through a field of barley plucked a few ears and on his arrival home threw them for his fowls into his garden and in due time a few of the grains arrived at maturity, and as the ears appeared remarkably fine I determined to try the experiment of cultivating them'.

A more elaborate version of this story appears in a paper by Arthur Young, F.R.S., Secretary to the Board of Agriculture, 1793–1808, in an extract from a MS. History of Debenham, 1845, in the possession of Mrs. Lock of Debenham, which reads as follows:

'About the year 1820, John Andrews, a labourer of Mr. Edward Dove, of Ulverston Hall, Debenham, had been

threshing barley and on his return home at night complained of his feet being very uneasy, and on taking off his shoes he discovered in one of them part of a very fine ear of barley—it struck him as being particularly so—and he was careful to have it preserved. He afterwards planted the few grains from it in his garden, and the following year Dr. and Mr. Charles Chevallier, coming to Andrews' dwelling to inspect some repairs going on (the cottage belonging to the Doctor), saw three or four ears of the barley growing. He requested it might be kept for him when ripe. The Doctor sowed a small ridge with the produce thus obtained, and kept it by itself until he grew sufficient to plant an acre, and from this acre the produce was 11½ coombs (about the year 1825 or 1826). This was again planted and from the increase thence arising, he began to dispose of it, and from that time it has been gradually getting into repute'.

The old variety of barley called in some districts 'Archer', and also known by several other names, but of which we have no definite account of the origin, is also quite well marked off from other barleys and has distinct characters, of which those most obvious are rather late ripening, a short neck and a grey-coloured grain. It is probably the old common English narrow-eared barley of the country, and as generally met with is composed of a large number of slightly differing races and is therefore not uniform in quality. It tillers more freely than other barleys and is a good yielder, and for this last character has gained on Chevalier in some districts. It is well suited to light soils but can be grown on almost any type of soil. On account of its valuable economic qualities many separate selections have been raised from it.

It is not unreasonable to suppose that even if left free from accidental mixtures one or other race of barley will tend to crowd out others when the soil and climate are more favourable to it, and it is obvious that with the average quantity of seed grown there is a good deal of natural selection going on. Taking the grains sown at three bushels per acre and assuming each plant that survives to average 1 to 1½ stems bearing 30 to 40 grains we can see that only one in two or three seeds will have produced plants which survive. Crowding out therefore must always be taking place. Attacks of insect pests and other external enemies of the plant in early stages will have

a general tendency to accentuate this process and we may be sure that it will be the most vigorous plant which will best resist such attacks.

Comparison of the Characters of Chevalier and Archer Barleys

The differing characters of these two barleys are liable to more or less fluctuating variation with cultural conditions, and in the following comparisons equal conditions of cultivation are assumed.

Chevalier and Archer barleys are distinguished botanically by a specific difference in the 'rachilla'. This is a small structure lying in the furrow of the grain. In Chevalier barley it is smooth or furry, whilst in Archer it bears distinct hairs or bristles. This character is independent of cultural conditions and may therefore always be used as a means of distinguishing the two classes of narrow-eared barleys. It does not, however, taken alone, serve to distinguish Archer from wide-eared barleys, because both types of rachilla are met with in the latter.

The colour of the grain of Chevalier is brighter than that of Archer and in consequence of the fact that the different Chevaliers are 'pure races', selected more recently, samples are generally more even in appearance than those of the Archer type. In respect of size of grain there is very little difference between the two varieties. The ear of the Chevaliers is slightly narrower and longer than that of the Archers; the ear of the latter emerges only a few inches and sometimes only just from the upper leaf-sheath. Chevalier being a longer-necked barley than Archer is more liable to fall over at the last 'knot' or node of the straw. In many seasons a good deal becomes 'knee-bent', which usually happens after the grain is ripe and in an interval during which adverse weather may prevent cutting. This defect seems to be directly due to the length of the internode between the last joint and the ear. Straw characters are associated, without doubt, to a great extent with soil conditions, but the character of the straw generally gives a great advantage to Archer and more especially on soils where straw is liable to be weak.

Plants of Archer and Chevalier grown side by side at Warminster showed the following average differences:

	Archer in.	Chevalier in.
Average length of straw from root crown to base of ear	33	35
Average length of last internode or 'neck'.	11	15

Now in Chevalier barleys the knots appear to be the weakest points, and if the last internode carrying the spike is very long it does not take much wind or rain to bend the straw at the last 'knot'. I have observed whole fields of barley with almost every stem 'kinked' at this point. The quicker the growth of the plant, the weaker are the knots, because growth of the young tissue of the stem takes place up to the time of ripening at just these points. Archer barley, with a shorter neck, seldom gets 'knee-bent' to the same extent, because the leverage of the ear acting upon the straw at the 'knot' is not so great. With 'knee-bent' Chevaliers there is some discoloration of the grain due to the ear falling near the ground, but the stem does not often break.

All the evidence I have seems to point to the fact that as between Chevalier and Archer types, the latter plant, with the stiffer straw and shorter neck, and a slightly longer growing period, is the stronger plant. Furthermore, it is also more prolific in yield of grain.

There is an important mass of conclusive evidence on these points derived from comparative trials and plot experiments carried out in Denmark; and some years later comparisons were made on an extensive scale by the Irish Department of Agriculture between these two types, and other old varieties.

In England, whilst there has been a great accumulation of individual experience on the relative values of Chevalier and Archer types, there has not been any extended or widespread series of comparative trials of the older races of barley.

I think it most desirable that a few of these non-hybrid races should continue in cultivation. From selected plants arising from crossing them again we might probably continue to improve on existing races.

Danish Experiments

Comparative trials and plot experiments were carried out in Denmark between 1893 and 1902 and I shall now refer to some records of these. I am indebted for these in the first instance to Mr. Harold Faber, who procured them for me at the request of the Board (now the Ministry) of Agriculture; also to Mr. Christopher Sonne (a prominent agriculturist in Denmark and for many years in charge of the experiments) for considerable information, with many reports, and a complete collection of plants and seeds. I am also indebted to the late Mr. Alan McMullen (formerly of Messrs. Guinness, Dublin) for a summary of the results in English weights and measures and for having pointed out resemblances between the respective Danish types and those known by other names in this country.

The acreage of barley in Denmark is about the same in proportion to the other cereals as in England, but owing to smaller local consumption admits of a considerable export. The following figures illustrate the climatic conditions of the barley-growing districts as compared with the North-East counties of England:

	North-East England	Denmark
	in.	in.
Average rainfall .	26	23
Mean temperature:		
Winter . .	39	32
Summer . .	58	60

The climate is therefore drier, colder in winter and warmer in summer than in our North-Eastern districts.

The barley-growing soils in Denmark are generally on boulder clay of the glacial drift, overlying Chalk.

The experiments to be described were organized and controlled by the Danish Agricultural Society. They were commenced in 1882, and for the first ten years a number of questions were investigated, connected with the time of sowing, quantity of seed, methods of harvesting and composition of grain. In some years trials were made on as many as 76 different farms all over the country, and to settle a simple point, like the average difference resulting from drill and broadcast sowing, no less than 230 comparisons were

made. It is, however, in the comparison of varieties that the great value of the Danish experiments consists. It is impossible to do more than indicate the elaborate methods taken to ensure fair comparisons. At each of five stations all the variety plots are quadruplicated year after year. There are twenty different plots for each variety in each year. In addition, for several years comparisons of yield and quality were made on a very large number of farms, so that (Mr. Sonne informs me) something like 1,000 samples each year are compared and records kept. There is no other series of trials of varieties of barley on record anything like so complete and reliable, and it is evident that they have been designed and carried out without omitting any of the many precautions which are necessary if experimental results are to yield reliable information for practical purposes. It is much to be regretted that a full account of what has been done has not been published in our language.

The following is a mere summary of the Danish results:

Thirty-three different sorts of two-rowed barley were compared. These may, with a few exceptions of no special interest, be divided into three groups corresponding to the three types of barley grown in England:

1. Prentice barley. This was named 'Prentice', and is still called Prentice in Denmark, because it was at first supposed to resemble barley of that name which was well known for several years before, but the barley actually used originated from 100 lbs. of English seed-corn of a mixed type imported in 1891. The progeny of this seed has been sown year after year up to the present. At present the barley is nearly all of Archer type. A sample sent to me in 1902 contained only 6 per cent. of barley of Chevalier type.

2. Selected Chevalier barleys of Swedish, Danish, German and English origin.

3. Wide-eared barley of Spratt or Goldthorpe type.

In the first year of the variety trials (1893) eleven sorts were compared, and all these same eleven sorts have been re-seeded year after year at a seed station devoted to this special purpose. Two were Prentice barleys, both derived from the original seed before referred to, but grown meanwhile in different localities. Five were Chevaliers, viz., three Danish sorts, one Swedish, and one English (Hallett's). Four

were wide-eared barleys, including Goldthorpe, and three others more or less similar.

The new sorts added since 1892 include selected Prentices grown up from single plants derived from the originally imported stock; several more recently introduced selected Chevaliers of English, Danish and German origin; new wide-eared sorts of English and German origin; and some cross-breds.

The barleys are valued year after year by a system of giving points for colour, shape and 'quality'. With regard to quality, the fairly constant inverse relation of this to nitrogen content had been well proved in Denmark before it was generally recognized in this country. Notwithstanding this, however, I find that the relative number of marks given does not coincide with what would be accepted as relative value for malting in this country. To give the figures in detail would therefore, as between the different types and varieties, be misleading.

There also have been carried out several series of malting trials, and as the result it has been established that low nitrogen, mellow grain, and high 'brewers' extract' go together.

The following tables show *in summarized form* the yields (1) for ten years with the eleven sorts above mentioned, and (2) for three later years with these, together with the newer sorts included.

TABLE VIII.—Ten Years, 1893 to 1902, Eleven Varieties

	Bushels per acre Average
Two Prentice sorts . .	42·4
Five Chevalier sorts . .	39·6
Four wide-eared sorts . .	37·2

TABLE IX.—Three Years, 1900 to 1902, Twenty-seven Varieties

	Average
Five Prentice sorts . .	42·0
Fourteen Chevalier sorts .	38·0
Eight wide-eared sorts . .	36·4

Stated in general terms, the evidence (with the conditions prevailing in Denmark) is that:

1. The different sorts of Archer type represented by 'Prentice' barley, whether grown from unselected or selected seed, are all very similar to each other both in average yield and quality in the same seasons.

They all give considerably higher yields than any other sorts. In quality, when judged by appearance they are not quite equal to Chevaliers, but in respect of nitrogen content and extract the differences are small.

2. All the Chevaliers are very much alike. They all give about the same yield and quality in the same seasons. The yield is not so good, but the quality judged by appearance is better than that of the Archer barleys.

3. The wide-eared barleys differ very much amongst themselves both as to yield and quality in the same seasons. The average yield is lower than that of Chevalier, and much lower than that of Archer. The average quality, whilst very variable with the different sorts, is always according to Danish ideas better than that of the Chevaliers, and better still than that of the Archers. Of the different sorts of wide-ears, Goldthorpe is very distinct from the others, and almost always gets more marks than any other sort. It also gave in two trials in 1891 and 1892 lower nitrogen and more extract than any other sort.

The question at once arises: How far can these results be applied to English conditions?

The barley-growing districts of Denmark are about parallel in latitude with those of the North of England and the South-East of Scotland, but the yearly average rainfall is lower. There is a much harder winter, and sowing is generally not before the second week in April, and often later. There is, however, higher temperature and the days are longer during the maturing period, and this period is shorter than with us.

The soil of the barley-growing districts in Denmark is much more uniform in character than in England. In respect of both soil and climate taken together the Danish conditions differ considerably from those under which barley is generally grown in the South of England, but more nearly resemble the conditions in the North. This comparison is perhaps too general to be of much service and I regret the lack of opportunity to make it more complete.

The higher yield of Archer barley must be due to the character of the plant, whether grown in this country or in Denmark, and this character is no doubt associated with the more sturdy straw and the slightly longer growing period of the plant, possibly also with a stronger root system. We know that the slower growing varieties of all plants are nearly always the most prolific.

I have observed that Archer is sometimes in our climate only very slightly later than Chevalier, and that when Archer and Chevalier are grown alongside and sown at the same time, and when sowing is early and the soil and season favourable, there is very little difference; but when sowing is late, and when the external conditions are adverse to quick ripening, then Archer sown alongside with Chevalier may be a week later at harvest or even more. In Denmark seeding is on an average three weeks or a month later than in the East and South of England, and we should therefore expect the difference in quality there to be more pronounced between the two sorts.

Whilst the differences between Chevaliers and Archers have not been much considered from the malting point of view in England, owing to the two sorts being a good deal mixed in cultivation, there is among growers and maltsters and brewers in different parts of England considerable difference of opinion on the relative merits of Goldthorpe and the narrow-eared sorts.

With regard to the low yield of Goldthorpe and the other wide-eared sorts, it is doubtful whether the Danish results would apply in the North of England. Their summer climate is drier than ours, and in a very dry atmosphere undoubtedly there is a serious loss from the ears of wide-eared barley breaking off. It is fairly certain that this is at any rate one cause of the lower yield. Generally speaking, Goldthorpes or other wide-eared sorts were grown in the North of England, and narrow-eared sorts in Norfolk and Suffolk and the Southern counties. In Scotland, what is known as Common barley is generally a mixture of Chevalier and Archer types. What is commonly called in Scotland Chevalier was more frequently than not wide-eared barley of one or other of the more recent of the older sorts. This is rather significant, because Chevalier is a term applied often loosely in Scotland

to the more even and brighter-looking barley of higher value, regardless of variety. In Lincoln, Chevaliers, Archers and wide-eared barley were met with, and it would be hard to say which was the most popular.

Local conditions of all sorts have, of course, determined this state of things; but it seems to be generally considered that the wide-eared barleys suit the later situations best, so far confirming the results of the Danish experiments.

The Danish results as far as they go have not shown that any one type of barley is better than others in respect of both yield and quality, but the Danish climate is against quality in the high-yielding Archer type, which, to get good quality, needs to be sown early, and, on the other hand, the conditions in Denmark seem to be more against yield in the wide-eared sorts than in England, owing probably to the ears breaking more readily in dry summers.

I shall now very briefly refer to some comparisons made between Archer and Goldthorpe by the Irish Department of Agriculture in Ireland, which have some bearing on the foregoing Danish experiments.

From 1901 to 1905 two-acre plots of several plots were grown alongside in some of the barley-growing districts of Ireland. Between 1901–1904 comparisons between Archer and Goldthorpe were made in the case of twenty-six adjoining plots of each race. Whilst there were many more cases in the Danish experiments where the yield was better with Goldthorpe, the average yield of the Irish plots was four bushels per acre higher with Archer barley.

The following table shows the average yields for each race in each year:

Table X

	Archer Bushels per acre	Goldthorpe Bushels per acre
1901 . .	47¼	38½
1902 . .	49	47
1903 . .	38½	33½
1904 . .	42	40¼
Average	44	40

With regard to quality, the Goldthorpes were slightly

better, but not nearly enough so to compensate for the lower yields.

English and Scotch Chevaliers were tested between 1904 and 1906, but did not give as good average results as Archers and were therefore discontinued.

The Irish results confirmed those obtained in the Danish trials, although the climate is so very different.

CHAPTER XII

NEW AND IMPROVED RACES OF BARLEY GROWN IN GREAT BRITAIN

EXTRAVAGANT claims are made for so-called (I say 'so-called' advisedly) 'new and improved' races of cereals, although at first sight it might appear fairly easy to secure very great improvement when we recall what has been done with roots, fruit and vegetables.

Louis de Vilmorin (1852) succeeded in breeding and selecting races of sugar-beet with double the sugar content of the older races. In the Napoleonic era the average sugar content of the roots was about 7 per cent. Many years ago I saw a certificate of a sugar-beet factory showing a farmer's delivery of roots averaging 19·9 per cent. by weight of sugar, and the percentage has probably increased of late years.

But the barley we use is the seed of a plant and we cannot modify the seeds of plants to anything like the same extent, or at anything like the same rate, as we can modify their somatic structure. We can, however, by selection and hybridization increase the value of our existing races of barley.

There are no official records of the area of races of barley under cultivation in England and we have only rather uncertain data on which to make rough estimates of the relative acreages in the past and present of different races. But I have been given the opportunity of looking through the records of entries for the Barley Competitions of the 'Brewers' Exhibition' for each year since the Exhibition started, in 1879. In these lists of entries for the years 1887–90, 83 per cent. of those to which varietal names were attached were Chevalier barleys. The prize lists are available only since 1911, but I think there can be no doubt that in all the earlier years the prizes for malting quality went to Chevaliers in as high a proportion as the entries. Anyway, the champion prizes went to Chevaliers in each of the four years 1911–14, when the proportion of Chevaliers had fallen to an average

of 56 per cent. Between 1886 and 1914 the names of about twenty-four races appear.

From 1919 (when the Exhibition was re-started, after the war of 1914–18) the entries of Chevalier barley went on steadily falling, and between 1926–36 only 2 per cent. of the named races were Chevaliers, and in no one of these years did a Chevalier sample get a champion prize. In 1938, of 58 entries 31 were Plumage-Archer, 19 Spratt-Archer, and 2 Golden-Archer.[1]

This record alone would afford only slight evidence of the spread of the new races produced, but the summarized figures (see Table XI) of the percentages of samples of barley tested by the Official Seed Testing Station at Cambridge give more substantial evidence.

It will be seen that the greatest number of samples were represented by the races Spratt-Archer, New Cross, Plumage-Archer, Plumage and Golden Archer. In the later periods Spratt-Archer and Plumage-Archer have gained on the other races. The number of Spratt-Archer samples in the later periods exceed those of Plumage-Archer, but taking all the Warminster-bred races into account it will be observed that they have fairly well maintained their numbers.

There is at least *prima facie* ground for assuming that Spratt-Archer and Plumage-Archer, of which the acreage must have about doubled in each of the first ten years after their introduction, and to an even greater extent since, have something to recommend them either to the grower or to the purchaser of the crop, or to both.

In addition to the evidence of the economic agricultural value of these hybrid races, which is afforded by their wide spread, and possibly is a part cause of their rapid spread, they have been very completely tested in systematic trials by the Department of Agriculture in Ireland and by the only responsible body in England which carries out such trials in widely separated areas, viz., the National Institute of Agricultural Botany (N.I.A.B.), at six different stations in England

[1] The old Chevalier strain is now practically extinct in this country and I think the chief reasons for its disappearance are that it has a weak straw, a permanent habit of kinking at the uppermost node or knot of the straw, and in consequence, in some seasons, a fair proportion of the ears nearly touch the ground; also it is not a high yielder. Farmers have found either Spratt-Archer or Plumage-Archer more profitable.

over a series of years, and as a result of these trials they have been recommended by the Institute to farmers in this country. The results of the N.I.A.B. trials are on record.

The 'Official Seed Testing Station' for England, established in 1922, and conducted for the Ministry of Agriculture by the National Institute of Agricultural Botany, Cambridge, receives for testing each year between 1,000 and 2,000 samples of barley from farmers and merchants, with varietal names attached. The table below gives the percentages of the samples tested over a series of years.[1]

TABLE XI

	Crop 1922/3	Crop 1935/6	Crop 1936/7	Crop 1937/8	Crop 1938/9	Crop 1939/40
Total number of named barley samples	1,088	886	1,376	1,496	901	1,571
New Races	%	%	%	%	%	%
Spratt-Archer	2·0	37·4	35·8	40·0	41·6	42·2
New Cross	..	4·9	5·5	4·8	3·8	3·3
Plumage-Archer	16·6	30·1	27·2	25·9	26·6	28·8
Plumage	6·4	10·5	12·3	10·6	10·0	9·6
Golden Archer	..	3·4	3·3	4·6	5·4	5·0
Totals:	25·0	86·3	84·1	85·9	87·4	88·9
[Warminster-bred races—% of above total	92·0	51·0	51·0	49·0	48·0	48·8]
Other Races						
Standwell	13·2	1·7	..	1·4		
Chevalier	12·4	1·5	..	1·5		
Archer [2]	10·2	3·4	1·9	1·9	..	2·0
Burton Malting	6·9	1·0				
Winter	7·6					
'1917'	5·0	0·3				
Maltster	4·4	1·2	..	1·5		
Goldthorpe	3·4	1·2				
Binder	2·7	0·3				
Other named races (all below 1 or 2%)	9·2	3·1	14·0	7·8	12·6	9·1 [3]
	100·0	100·0	100·0	100·0	100·0	100·0

Part of the history of Spratt-Archer and Plumage-Archer has been written by Dr. H. Hunter (1926) in his very valuable and unique contribution *The Barley Crop*, wherein is given a

[1] See Journals of N.I.A.B.
[2] Mostly 'Beaven's English Archer', distributed in 1905.
[3] Includes more recent Warminster-bred races, distributed since 1932.

detailed account of the most extensive series of experiments with barley, considered as malting material, which has ever been carried out in the United Kingdom. This account relates much which is of value to farmers, maltsters and brewers alike, and more than has ever before been brought into so small a compass.

> *Spratt-Archer* is a hybrid race, selected by Dr. Hunter in 1908. The Archer parent was one of the selected Prentice barleys, all descended from a small stock of English Archer barleys. The Spratt parent originated in the nursery at Warminster. The first field crop of Spratt-Archer was grown in England in 1920.
>
> *In the early nineties I had been buying a quantity of Spratt barley (at that time grown quite widely in the Fen districts) and I made several selections of different races of Spratt, one of which I multiplied and sent to the Irish Department of Agriculture. It was grown on some of the peaty soils in Tipperary, and it was from this particular barley that the Spratt parent of Spratt-Archer originated.*
>
> *Plumage-Archer* is a selected hybrid race resulting from the cross-fertilization at Warminster, in 1905, of two 'pure races' selected at that station, viz., 'Plumage' and 'Archer'.

These two hybrid races are two-rowed barleys, but not of the Chevalier type. Fig. 16 shows typical ears of (1) Spratt-Archer and (2) Plumage-Archer.

Probable Cause of the Spread of the New Races of Barley

Between 1922 and 1929 amongst the principal races of barley cultivated in Great Britain were Plumage-Archer, Spratt-Archer, Plumage, Standwell, New Cross, Burton Malting, Chevalier, Goldthorpe, Pembroke, Archer Stiff Straw, Binder, Beaven's Archer, Archer, Golden Pheasant. Subsequently, of the newer hybrid races the most extensively grown were Plumage-Archer, Spratt-Archer, Standwell, New Cross and Pembroke.

It would be interesting and instructive to seek for the cause of the rapid spread of some of these new races, notably, the two first-named.

The estimates of the Ministry of Agriculture for the average yields of barley in Great Britain during the years 1922 to 1929

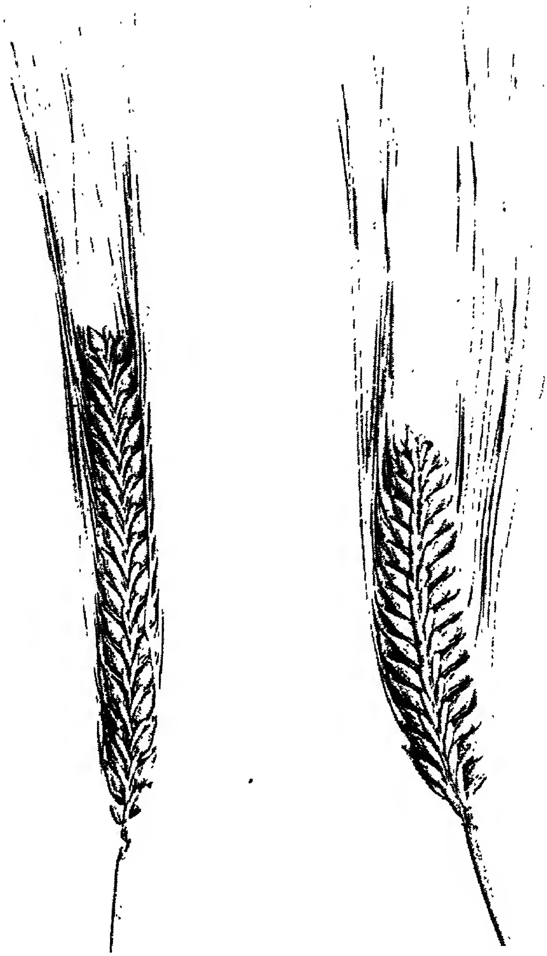


FIG. 16.—(1) Spratt-Archer. (2) Plumage-Archer.

To face page 104

inclusive indicate that there was a steady increase in yields of barley amounting to about 6 or 7 per cent. for the average of these years compared with the previous ten years. This continual rising productivity was probably partly due to good seasons, but I think still more due to the introduction and spread of the more productive races. This was fairly evident to all observers, and to myself in particular, because in almost every one of those years I visited at harvest time every considerable barley-growing district from Somerset to Fifeshire.

I submitted the figures above referred to to Dr. F. G. Gregory, of the Department of Plant Physiology and Pathology, Imperial College of Science and Technology, London, for statistical examination, and his conclusion was that the probabilities against this sharp increase being a fluctuating result were overwhelming.

The regularity of the increase compared with the seasonal fluctuations of the previous period negatives the conclusion that good seasons contributed to any considerable extent.

It was also noted that for the same period other crops, such as roots and hay, showed no such steadily rising yields in these years. We may therefore look to some cumulative cause for these results, such as:

1. *Reduced acreage.*—The acreage of barley in Great Britain (excl. Ireland) dropped from 1,728,000 acres in 1910 to 1,521,000 in 1922, and dropped again to about 1,220,000 acres in 1929, with a slightly falling yield with considerable fluctuations in the earlier period and a steady and considerable rise in the latter period.

This gives no indication that reduced acreage has generally tended to increase yields. Furthermore, between 1885 and 1895 there was a fall in the wheat acreage in the United Kingdom of more than one million acres, viz., from 2,553,000 to 1,456,000; and again between 1898 and 1903 from 2,158,000 to 1,621,000. In neither period was any correlation shown between acreage and yield. These facts appear to negative the conclusion that the falling acreage accounted for the increased yields.

2. *Effect of sugar-beet preceding the barley crop.*—There has been a progressive average increase since 1922 of the area under sugar-beet and this has no doubt been followed by

higher yields of barley where barley has followed this crop. The acreage under sugar-beet during 1922–29 averaged about 7·5 per cent. of the barley area.[1] If in that period 50 per cent. of the sugar-beet acreage were followed by barley (a high estimate), and if the consequent increased yield were 10 per cent., the average yield of barley in Great Britain would have increased from this cause by only about 0·4 per cent.

3. *Increased use of nitrogenous manures.*—Comparing 1927 with 1913 the position with regard to the quantities of artificial manures used in Great Britain (as estimated by the International Institute of Agriculture) was as follows:

Potash manure . . .	About stationary.
Superphosphate and basic slag .	Decrease of about 300,000 tons.
Nitrogenous manures, viz., sulphate of ammonia, nitrate of soda, synthetic nitrate, etc., and guano.	Increase of about 30,000 tons.[2]

4. *Higher yielding races.*—The evidence that the new races introduced have contributed largely to increased yields is, I think, conclusive. It is contained in the reports of:

1. The Irish experiments from 1909 to the present date.
2. The N.I.A.B. variety trials.
3. The Essex N.F.U. census in two successive years.
4. Returns of the Ministry of Agriculture relating to races.
5. The relative number of samples of the higher yielding races sent to the O.S.T.S.

The operations of (1) and (2) carried on systematically over a long series of years have no doubt also contributed to increased yields.

Economic Value of the Increased Produce

An increased yield of 6 to 7 per cent., assuming that all of it has been sold, or used, in place of imported barley only,

[1] The average acreage under sugar-beet in Great Britain for the ten-year period 1929–38 was 322,000, or 32·5 per cent. of the barley acreage over the same period.

[2] This estimate of increased applications of nitrogenous manures is probably a fair estimate because it credits the whole of this increase to arable land and ignores the greatly reduced rate of phosphates.

has been equivalent to an increased net annual return to the farmers of about £750,000, or £6,000,000 in eight years.

On the evidence available it is fair to assume that £500,000 of this is due to improved races, equal to about eight shillings per acre on the whole barley area of the country, and to probably more than this on the acreage of the improved races, taking into account that these have been well proved to give not only higher yields but also better quality grain. This figure compares fairly closely with the available data for the increased value per acre of the new races.

These results may be expected to continue as long as new races are exhaustively tested for both yield and quality before distribution.

CHAPTER XIII

PRODUCTIVITY AND QUALITY

For agricultural purposes we have to breed for both productivity and quality and we can make no substantial progress unless we can identify these factors. We must put productivity first because the question is becoming more and more important and is necessarily the main concern of the farmer.

The productivity of any crop, that is of any aggregate of plants growing side by side, depends entirely on environmental *extrinsic* conditions and on the *intrinsic* heritable and persistent characters of the seed, and the effects of these two sets of conditions interact at all stages of the life of the plant and therefore jointly affect both the productivity and the quality of the grain.

Both yield and quality of produce are 'responses' of the race to environment in as great a measure as they are fixed characters of the race, and an important part of the problem in plant breeding, as in animal breeding, is to discover the responses of the race to its environment. In individual plants it is often, but not always, possible to distinguish variations which are inherited from variations resulting from environment.

Yield of grain per acre is determined by relations between the plant and its surroundings and by responses which the race makes to the soil and environment in respect of its seed formation. Yield also depends to a great measure on maturation of the grain, assisted by continually favourable weather at the time when the grain is filling out in the last stages of its growth.

It is very important that growers should select high yielding races and preferably those which will at the same time give good quality grain. It is fairly clear that a race with a long growing period is likely to give a better yield than one with a short growing period, and therefore it is probably desirable to select for any locality a race with as

long a growing period as the ordinary climatic and farming conditions of that locality permit. Differences in yield between good and inferior races may be considerable, whilst characters like standing power of the straw may make or mar the harvest. Yield is not simply prolificacy. One may have exceptionally prolific plants, but unless there are enough of them one does not get a crop.

With regard to quality, a definition is the first essential and then the factors which contribute must be isolated. A definition of quality which would be generally accepted presents a host of difficulties. Assuming grain to be of possible malting quality in respect of ripeness, condition and vitality, which are essentials and fairly well indicated by the colour of the grain, it would be a good thing if we could further define quality in terms of something which is intrinsic in the grain and which is also related to the same conditions of cultivation which affect yield. Quality (for which the farmer gets some extra return) cannot in fact be defined in scientific or, as far as I know, in any other sort of language. It is a matter of so-called 'expert' judgement in relation to the use to which the better kinds of barley are put, viz., to the manufacture of what we know as our national beverage. I suggested forty years ago in various published papers that 'quality' in this sense had some connection with the ratio of the carbohydrate to the nitrogenous matter of the endosperm and now there is a tendency to have regard to this ratio. Sir Rowland Biffen, I believe, found it useful in selecting wheats and I have myself persistently selected in the F.2 and subsequent generations for low nitrogen content. The fluctuating variability due to environment in this respect is, however, so great as to make this selection a lengthy and tiresome business, and disappointments are much more frequent than successes.

In wheat, quality is mainly a matter of 'strength', and strength generally goes along with high nitrogen content.[1] With barley it is, as far as analogy is permissible, in many respects the opposite of strength and goes along with low nitrogen content. We are told that for flour there is a scale

[1] Comparative 'strength' in wheat appears to be quite definitely a racial character to a great extent independent of external conditions (see 'Inheritance of Strength in Wheat', Biffen, *Jnl. Agric. Sci.*; iii, 86, 1908).

called 'bakers marks'. Probably the number of bakers' marks which a certain wheat will give depends to some extent on the methods of the miller. Certainly if a scale of brewers' marks for barley is ever adopted, something will depend on the maltster, but assuming, to simplify matters, that the maltster does his best, how would brewers' marks be given? Bakers' marks have something to do with the size of the loaf and the brewer has a scale which in a way corresponds, called 'extract'. A given weight of barley ultimately gives a certain weight of extract and the amount of this depends partly on the size of the grain and partly on what is called 'free working' quality, which latter character is closely associated with low nitrogen content.

In England, the quality of barley often counts far more in value per acre (within limits) than does yield, and should therefore be taken into account to a greater extent than has been the practice hitherto. Like the 'strength' of wheat it depends largely on growth and maturation, but in this country barley rarely reaches the stage of full growth and full ripening, except perhaps in a few favoured spots on the East Coast in an exceptionally good season, for reasons such as excessive rainfall and lack of sunshine, or drought causing premature ripening.

Soil, weather, and the farmer, all taken together, have more influence on the quality of barley for any purpose than has the plant breeder.

Variations in quality, apart from variety, are for the most part due to climatic conditions. Seasonal influences certainly outweigh all others. More often than not the grain never really gets filled out with starch. Season mainly determines quality, and quality in the old sense meant maturity.

To ensure good quality in barley the ears should be slightly bent, the grain hard with wrinkled coat and the straw dead ripe. Unfortunately dead ripe straw has a low feeding value, but in any case barley straw has not, on the whole, a high reputation as feeding material for animals in this country.[1]

When considering quality the question of 'lodging' should

[1] The decline in the acreage of barley in the grazing and dairying districts has probably come about because oats can be used when less ripe than barley and the straw makes better cattle-food.

not be overlooked. It is generally the heavy-yielding crops that go down. Just as the grain is ripening off the whole plant leans from the crown of the roots, which is generally about half an inch under the surface. This can hardly occur without the roots being loosened to some extent. The incidence of 'lodging' therefore usually depends on the condition of the soil or the strength of the roots. Incidentally, it must be remembered that 'lodging' increases the cost of harvesting.

Extrinsic Factors of Productivity and of Quality

As with all other farm crops, the main factors of productivity and also of quality are the soil and the seasons. Furthermore, there are complex relations between these conditions on the one hand; and on the other hand, the racial characters of the plant.

Soil

Soil conditions, dependent temporarily on weather but mainly on physical and other conditions which determine its texture and tilth, such for instance as distinguish loams and clays, are largely uncontrollable by any methods of cultivation.

The natural character of the soil determines whether on any average of years barley is a profitable crop to grow. It is unfortunate that the soil conditions which generally favour yield are frequently not those which give good quality. There are many soils, and even districts, which rarely grow barley of good quality. As good a plant of barley as of wheat (sometimes too good) can be produced on a good soil, but with the best of weather maturation will be wrong and consequently the quality three years out of four will be coarse. There will be too much vegetation and seed formation will be too prolonged. A very poor, hungry soil, on the other hand, may give good quality with an extra favourable season, such as will conduce to growth without check: just enough rain to enable the plant to make the best of what there is in the soil: and not too much drought to shorten the period of grain formation unduly and so give premature ripening.

In the long run the best barley soil is that of medium natural strength: light medium perhaps rather than heavy

medium. A marl is not so good because it is generally heavy medium.

In respect to adaptation of races to soil conditions within the limits of the English barley-growing areas, wide-eared, two-rowed barleys are more generally grown on the richer soils and narrow-eared on the lighter soils.

We cannot at present explain why one race of barley may give good results on a soil on which another will give bad results, but if we knew more about the parentage of our races we might be in a better position to offer some rational explanation instead of having to be content with empirical results, and to depend mainly on experience. Races of barley have acquired their special habits along with their particular structure as a result of exposure through many generations to special conditions, and along a line of research which will tell us the past history of our present races we may arrive at useful results and get to understand why they are respectively suited for particular soils.

Seasons

Weather conditions affect quality of grain quite as much as, or more than, soil conditions. Fortunately good weather conditions, unlike those of the soil, favour good quality as well as grain formation and good yield.

As to weather conditions generally, good barley growers for the most part are of opinion that an essential for quality is that the plant shall grow without check. Too dry a seeding time means of course an unequal start. The influence of weather at later stages varies so greatly with different soils that even if the same weather conditions prevailed (as never happens) in different parts of the country, it is fairly certain that some districts would give better results in one season and others in the next. All the various conditions have far less influence on the yield and quality of barley than the seasons have. Adverse atmospheric conditions may easily affect the bulk of the crop in this country to the extent of 30 per cent.

Weather does not affect all races of barley to quite the same extent, but it affects them all approximately to the same extent. If the weather of two consecutive years made a

difference of 10 per cent. in the average yield of two races, it might make a difference in the same direction of 8 per cent. to one and 12 per cent. to the other. That would be about the limit.

In any field on which barley is grown as a farm crop, under normal conditions of culture and race, seasonal conditions being the only variant, the 'probable error' of the yield of barley due to climate alone is of the order of 4 cwts. per acre where the average over a long series of years is 20 cwts.

The dependence of both productivity and quality on a combination of soil and atmospheric conditions is illustrated in Table A (Part II, p. 366), cols. 1, 2, 4, 5, 9 and 10, which show (a) average number of surviving plants per square yard; (d) average number of ears per plant surviving at harvest; (e) average weight per ear; (M) the migration coefficient: ($y \times \cdot 08$) = approximate cwts. of grain per acre; (n) average nitrogen per cent. of dry grain; for different races (not always the same but chosen for some special qualities), in 25 successive years on replicated chequer-board plots in the barley nursery at Warminster.

These figures show that not only is produce of grain dependent on these external conditions, but also that all the characters of the plant and of the grain vary with these conditions. It is of course impossible to keep any patch of soil, however small, always in possession of the same supply of plant nutrients, and the condition of the soil in this respect interacts with the seasonal conditions. This accounts for the wide differences in yield from year to year on the Warminster nursery plots, although the area of them is only about fourteen perches and is the same year after year.

In addition to these largely uncontrollable conditions, it should be remembered that barley has many enemies, such as birds, hares, rabbits, mice, etc., as well as wireworm, thrips, gout-fly, etc.

Gout-fly (*Chlorops Taeniopus* Meig.)

Low yield in England is without doubt largely due to the ravages of the gout-fly. In some seasons this insect causes serious damage to barley crops. In 1937 a farmer friend of

mine (one of the best barley growers in Wiltshire) told me that the infestation of gout-fly was going to lose him half his crop. Seeing that he was growing some of my new hybrids I was very much concerned and made a careful inspection of his fields.

In the first big field in the Wylye Valley, which had been sown rather late on land which had evidently been more or less waterlogged in the early spring, I estimated that more than half the plants had failed to mature and that this failure was largely due to gout-fly. I put the probable yield at 3 quarters per acre. In another much larger field, on higher ground and on much lighter land, the attack was only slight and the yield looked like being somewhere about 6 quarters. This field had been sown rather earlier than the former. Both fields were growing Plumage-Archer.

On an adjoining farm I found an eighty-acre field of Spratt-Archer, which looked like a 3 quarter crop. It was as badly infested as the first field inspected. It was on high ground, certainly not waterlogged, and sown late in April. There was also another large field of Spratt-Archer, sown earlier but nearly as badly attacked. All this land was well farmed.

I visited in the same year various fields of barley in Wilts and Berks between Warminster and London, and every one of them had more or less bad infestation, always more severe on the lower-lying and later-sown fields.

I found more gout-fly on these inspections than I have observed in any previous year whilst on barley tours. In some fields it was probably responsible for reducing the yield to the extent of 50 per cent.

At Cambridge plant-breeding station in 1937 big patches of barley were decimated by this pest, and Dr. Hunter estimated that the damage done to farm crops in general in that year was over 10 per cent. more than usual.

My own conclusion is that in this particular year we were suffering from two broods of gout-fly. The first brood, owing to suitable weather conditions, attacked the young plants some time late in May and destroyed them; and the second brood (probably about a thousand times more numerous) attacked the plants at a later stage, when fortunately less harm could be done.

Gout-fly in 1937 was less prevalent in the North of England (and in Scotland), where the yield was much higher than in the Eastern counties.

I suggest that the degree of severity of gout-fly attack depends on the extent to which the date of emergence of the fly from its winter quarters (which time is variable with weather conditions) coincides with a stage of growth of the barley plant favourable to the insect, but variable with local climatic conditions and with time of sowing. Some late-sown barley escapes, or suffers slightly, so it seems that a bad attack of gout-fly may not always be due to late sowing.

Some way of exterminating this pest should be discovered, for it is responsible in this country, in some years, for damage to the extent of many hundred thousands of pounds. It is the only serious barley pest we suffer from and it should be very systematically investigated.

Intrinsic (or Genetic) Factors of Productivity and of Quality

As between different races of barley there are inherited differences, and the first thing a plant breeder should do is to satisfy himself as to which are the intrinsic factors of productivity and of the quality of the produce to be aimed at.

I think it is fairly obvious that, first, one must have vigorous individual plants and that the degree of vigour can be estimated by the number of shoots produced from each seed. Some sorts of barley tiller more freely than others. Of course extra tillering capacity is not required if the ground has been seeded thickly because the ground will not carry more than a certain number of stems, but it is certainly of value when the crops have become badly thinned by adverse conditions. Secondly, the individual plant must be capable of migrating the reserve material accumulated in the stems and leaves into the seed, or, in simple language, of producing a high ratio of grain to straw. Then we can proceed to discover, if possible, whether these attributes are differentially inherited as between races and set about breeding and selecting for them.

There is a very marked difference as between different races in the proportion of grain to straw. In some seasons

the grain threshes out of the straw better than in other seasons and I have no doubt that what holds good as between different seasons and different soils also holds good as between different races. If a plant has a good seed-forming energy that, in my opinion, is one of the most valuable characters a race can possess.

I have learnt from my own nursery and field cultures, and from the study of different races of barley in this and other countries, that on any one area, large or small, there may be differences in value between two races in any one year, due to the inherited characters of the seed, amounting to at least 20 per cent. We therefore may safely say that racial character is an economic factor of great importance even if it has not as much effect as the extrinsic factors. Immunity from certain diseases is also a racial character, but is more or less independent of external conditions.[1]

The intrinsic, heritable characters are more or less under our control and much can be done by experimentation followed by biometrical analysis of our material. If, for instance, we cannot profitably grow any race of barley, or perhaps any other cereal, with less rainfall than an average of ten inches per annum, we can by experiment ascertain which race will best multiply under such and other adverse circumstances, or that method failing we must construct such a race by hybridization, or possibly by repeated hybridization.

Nitrogen Content and Malting Quality

Lawes and Gilbert (1857), writing on this subject, seemed to take it for granted that high nitrogen content of the barley grain goes with low quality and, inversely, low nitrogen with high quality, but they never seemed to follow up the idea.

They say: 'It has been seen that an increased percentage of nitrogen by the use of it in manures is, if beyond a comparatively narrow limit, most probably accompanied with a depression in those qualities which in practice give high rate of value to the corn. This applies more particularly where

[1] See 'Inheritance of Disease Resistance', Biffen, *Jnl. Agr. Science*, ii, 109, 1907; iv, 421, 1912.

the demand is chiefly for malting purposes. Upon the whole, then, slightly larger proportional return of nitrogen in increase for nitrogen supplied in manures, where the larger amounts of the latter were employed, is but a very questionable advantage'.

Munro and I (1897) furnished a mass of evidence (mainly derived from Rothamsted) that what at that time was commonly called 'quality' was, in point of fact, 'maturation', and that this was generally associated with low percentage nitrogen content due to relatively more favourable carbohydrate assimilation.

The subject of nitrogen content in relation to malting quality seemed a 'dead letter' in this country for about twenty years until the late H. F. E. Hulton (1922) collated all the more important results of previous investigations on this very difficult subject. Still later very valuable contributions to this subject were made by Dr. L. R. Bishop (1930) and we are now obtaining more light on the problem. Dr. Bishop's work, which has been added to since 1930, greatly elaborates the conclusion, based on some further experiments made by Munro and myself (1900), namely, that low nitrogen content of barley is generally associated with high brewing extract, although, of course, this is not the only character of the grain which is essential to the maltster and brewer.

It was then, and still is, quite certain that the market value of barley, as judged by experts, is much more often than not lower for high than for low nitrogen barley. In fact low nitrogen content in barley is considered to be an index of high quality.

The Barley Valuation Committee of the Institute of Brewing, for the years 1929–34, valued 144 pairs of samples, each pair representing two races grown alongside each other on the plots of the National Institute of Agricultural Botany at five or six different stations in England: the nitrogen content of the samples dealt with not being known to the valuers. In 67 cases the pairs were valued in the reverse order of their nitrogen content, the average difference being ·075 per cent. of nitrogen. In 61 cases the valuation was the same for each sample of the pair; and the average difference in nitrogen content was ·062 per cent. In only 16 cases out

of the 144 were the higher nitrogen barleys valued above those of lower nitrogen content, and in these cases the average difference between the pairs was very low, namely, ·037 per cent. From my own experience I should put the average error of sampling and of analysis at about equal to this latter quantity.

In our climate, and with our general farming conditions, we are not at all likely, even if we try, to produce races of barley with too low a nitrogen content. There will always be plenty of high nitrogen barley in the world and for this reason I personally should continue to breed races for low nitrogen content.

CHAPTER XIV

EFFECTS OF CULTIVATION ON PRODUCTIVITY AND QUALITY

Period of Sowing

Generally speaking, within the United Kingdom, conditions which admit of early spring sowing and relatively early maturation are those which give the best quality barley. The period of sowing depends largely upon the character of the season and of the land. March is the typical barley-sowing month in England, but barley may be sown as early as February if the soil is fit, or even as late as May. The best plan is to fallow and sow as early as possible: early sowing being more conducive to good quality and often to high yield, and to lower nitrogen content in the grain, which means a crop of high malting quality. Also the advantage of early sowing is that spring droughts are often avoided.

Lisle in his *Observations* referring to this subject says:

'It was Christmas (*anno* 1702) and farmer Biggs, farmer Crap, Mr. Bachelour, and farmer Hascall were with me: I proposed to them the advantage of sowing barley and summer-corn earlier than they did by a week or a fortnight, in case the land was in any good heart, and in dust, for the damage by what might die by bad weather would not come to so much as was always lost by drought. Farmer Biggs and farmer Crap were of my opinion, but Mr. Bachelour differed from us, which seemed to arise from his sowing poor land early, but I grounded the supposition on the land being in good heart; however we all agreed, that the earlier barley was sowed the finer it was, and the later the coarser, which must arise from the first having its growth from its earing in a hotter time, whereas that sowed later has much the colder time; so rath-ripe barley is generally the finest' (p. 93).

In the South and East of England barley is usually sown in February or March. In the North-East of Scotland sowing is generally approximately a month later.

I have no evidence myself that low yields invariably follow late sowing. Yields are always higher in Scotland and in Ireland, with invariably later sowing than in England, and generally higher in Yorkshire than in Norfolk, again due to the later sowing period in Yorkshire.

Races with prostrate habit are suitable for autumn-sowing: they make more growth of root and less growth of stem, but tiller well during the winter and are more frost-resisting. In the case of barley where winter-hardiness is of first importance the ordinary six-rowed winter forms are the most satisfactory. In some cases both Spratt-Archer and Plumage-Archer, the two more recently produced hybrids, survive the winter satisfactorily, but they are not winter-hardy in the accepted sense.

Nitrogen Content in relation to Period of Sowing

During the period of grain formation the combined soil and weather conditions are the predominant factors determining the ratio of nitrogenous content to carbohydrate of the grain, and the length of the growing period during the vegetative stage is not a material factor.

Whilst there is probably a difference of up to ·25 per cent. in the nitrogen content of any 100 grammes of barley as between different years with spring sowing every year, I should expect a very much lower difference as between winter and spring sowing in the same year. But it would take a great many years of experimentation under differing conditions of soil and climate to determine whether the average nitrogen content was higher or lower with winter sowing and the consequent earlier seed-forming period.

It would be interesting to see how far it is possible to predict nitrogen content from weather effects. I think it is certain that the plant generally accumulates a large proportion of its total nitrogen early in life; and that it migrates most of its nitrogen to the seed late in life; also that the accumulation and synthesis of carbohydrate is checked by drought, the net result being generally high percentage of nitrogen content in the grain in droughty seasons. This being the case, it would seem that as early sowing as possible in order to check the effects of this latter condition would be advisable.

Rate of Seeding

The amount of grain to be sown is usually determined by the condition of the soil and the season of drilling. Thick seeding improves the quality without affecting the yield. Thin seeding and excessive tillering nearly always give coarse grain. The usual seeding rate is from $2\frac{1}{2}$ to 3 bushels (=140 to 168 lbs.) per acre, but barley can be sown even more thickly with advantage. The rate of seeding, however, depends largely on the tillering capacity of the race and it is very important to select a race which, given good weather conditions, will produce well-developed grain. Most farmers in good districts sow 3 bushels to the acre and are of the opinion that a moderately thick plant conduces to 'kindliness' but not to large grain. I think it is fairly certain that by sowing 3 bushels to the acre more ears and smaller ears will be obtained than by sowing 2 bushels, and there will be lower nitrogen content and *ipso facto* better malting quality, but in respect of yield one will lose as often as one will gain.

Lisle says:

'Four bushels of barley is generally the quantity allotted to be sown on one acre, but, if the ground is very good, they may sow five bushels' (p. 95).

The grains should be sown at a depth of something between one and three inches according to the nature of the soil. Two inches is the usual depth aimed at as producing the most vigorous young plants, but if the soil is extra dry a depth of three inches is more favourable to good results.

The following table gives approximate figures for, (1) and (2), the percentage survival rate of the number of grains surviving per square yard at different rates of sowing; and (3) the respective crops obtained as results of survival of plants per square yard and number of ears per plant at varying weights of grain per ear.

[Table

TABLE XII.—Relations of (1) Seed rate; (2) Survival rate; (3) Yield—(*a*) per Square Yard, (*b*) per Acre

Equivalents—

Lbs. per acre × ·0937 = grammes per square yard.

Gms. per square yard × ·024 = qrs. (448 lbs.) per acre.

Wt. of 1000 grains (dry) 33·6 gms. = 40·0 grammes with 16% moisture.
1 grain = ·04 gramme.

Wt. of 1000 grains (dry) 37·8 gms. = 45·0 grammes with 16% moisture.
1 grain = ·045 gramme.

Wt. of 1000 grains (dry) 42·0 gms. = 50·0 grammes with 16% moisture.
1 grain = ·05 gramme.

(1) and (2) *Seed Rate and Survival*

Weight of a seed-grain (raw) (gm.)	Lbs. per acre sown	Number of grains per sq. yd.	Number surviving per sq. yd. = viability.	Survival rate %
·04	112 $\times \frac{\cdot 094}{\cdot 04} =$	263	50 100 150	19·0 38·0 57·0
	140 $\times \frac{\cdot 094}{\cdot 04} =$	329	50 100 150	15·2 30·4 45·6
·045	*112 $\times \frac{\cdot 094}{\cdot 045} =$	234	50 100 150	21·4 42·8 64·2
	140 $\times \frac{\cdot 094}{\cdot 045} =$	292	50 100 * 150	17·1 34·2 * 51·4
·05	112 $\times \frac{\cdot 094}{\cdot 05} =$	210	50 100 150	23·8 47·6 71·4
	140 $\times \frac{\cdot 094}{\cdot 05} =$	268	50 100 150	19·0 38·0 57·0

* Estimated approximate average for U.K.

(3) *Crop*

No. plants per sq. yd.	Ears per plant	Ears per sq. yd.	Wt. grain per ear Grammes	Wt. grain per sq. yd. Grammes	Quarters (448 lbs.) per acre
50	1	50	0·7	35	0·8
			1·0	50	1·2
			1·3	65	1·5
	2	100	0·7	70	1·7
			1·0	100	2·4
			1·3	130	3·1
	3	150	0·7	105	2·5
			1·0	150	3·6
			1·3	195	4·7
100	1	100	0·7	70	1·7
			1·0	100	2·4
			1·3	130	3·1
	2	200	0·7	140	3·3
			1·0	200	4·8
			1·3	260	6·2
	3	300	0·7	210	5·0
			1·0	300	7·2
			1·3	390	9·3
150	1	150	0·7	105	2·5
			1·0	150	3·6
			1·3	195	4·7
	2	300	0·7	210	5·0
			1·0	300	7·2
			1·3	390	9·3
	3	450	0·7	315	7·5
			1·0	450	10·8
			1·3	585	14·0
Probable averages for U.K.—					
100	1·7	170	1·0*	170	4·1
Averages for 8 yrs. in Warminster chequer-boards—					
95·4	2·17	208	1·0	202	4·8

* 25 grains per ear at ·040 raw, or 20 grains per ear at ·050 raw.

Spacing

The general theory is that when there are gaps between plants yield suffers. It is true that with the type of drills used hitherto spacing was often quite uneven, but in my opinion uneven spacing in general farming practice is due to a far greater extent to other manifold causes than to the admitted irregularity due to the type of drill used. At the same time it would be an excellent thing if a drill could be made which would deposit the seeds at exactly accurate intervals, say, one inch apart in the row.[1]

Very wide planted barleys are coarse and nitrogenous compared with those planted closely. I well remember an amateur farmer, who lived in my district, drilling a piece of good land with barley about fifteen inches apart, with the result that an enormous crop of straw was produced with excessively large grain of coarse quality. Of course close planting can easily be carried too far, and no doubt long experience has taught growers approximately the best conditions, in this respect, for different soils, but it is certain that one very common cause of uneven samples of barley is uneven plant growth on closely contiguous areas of the same field. Birds, wireworm and other enemies destroy many young plants, and the consequence is that the remainder are unevenly distributed and some get much more soil space than others.

I have been growing barley hand-planted on the nursery scale for forty years with even spacing, and there is no doubt that there is more uniformity in appearance than is obtained on field plots under otherwise as nearly as possible similar conditions. On examining my nursery and field plots I have observed that conditions other than spacing in plots of the same races in the same year would always vary. I must admit, however, that in looking through past records I have not found that even spacing gives intrinsically better value.

As to quality, the market value of barley is much influenced by uniformity in appearance of the sample, more in fact than

[1] Mr. Leake, writing in 1931, informed me that he had developed a new type of drill with a distributing mechanism designed to give greater regularity in sowing, and there is no doubt that with the more recent type of drill we get a better distribution of seed and increased yields; also there is a considerable saving of seed.

results justify, and I have no doubt that barley with even spacing is more uniform in appearance.

A great deal of work has been done and written upon the subject of spacing by Professor Engledow of Cambridge in relation to the cereals in general and its effect on yields.

Manuring

Unless the land is very poor it is not considered necessary to apply manures to barley for spring sowing after roots or grass, but it is sometimes advisable to do so when one cereal crop follows another in rotation. To produce a remunerative yield barley generally wants some artificial help after another white-straw crop, and I think very few farmers would grow barley after another corn crop from which all fertilizers had been withheld. Indeed artificial fertilizers, properly used, have a high value for crop production, and I believe that the farmers of this country, even before 1939, spent about £6,000,000 annually on these.

Results do not lend much support to the view that starvation conditions are necessary for the production of good-quality barley, and, as a matter of fact; absence of potash is distinctly detrimental to quality. Where quality is not an essential, the land should be in as high a condition as the straw will stand up to. A sufficiency of mineral manure favours both early ripening and good quality.

On very light soils the following fertilizers are recommended: 1 cwt. sulphate of ammonia, 3 cwts. superphosphates, 2–3 cwts. potash salts to the acre, applied at time of sowing (usually mixed with the seed in the drill) and harrowed in with the seed. On heavier soils potash may not be necessary.

Before definite conclusions can be arrived at as to the effects of manuring on quality of barley, samples should be obtained and examined over a long series of years, because there is nothing more certain than that soil and weather conditions have more effect on yield and quality than has manure.

A good illustration of this was afforded us in the season of 1921. It was then seen that under conditions of drought (which are starvation conditions) the best-farmed and most fertile soils gave not only the best yield but the best quality.

This was specially marked in Essex, where good races of barley yielded up to eight quarters per acre of better quality than was grown elsewhere in the United Kingdom.

Experiments with manures have formed a very small part of my scheme of barley breeding. Those that I have made may possibly add something to the knowledge of the application of specified doses of particular forms of manure to barley land, but no such prescriptions can be of much use to the individual farmer, because the amount of added plant food of any description required to produce a profitable crop will always depend on the condition of the soil before its application, and of this only the individual farmer himself can be the judge. I should say that the practical experience of the best farmers of to-day leads them to give barley as much plant food as the particular race grown can be expected to stand up to in an average season, and there is no doubt that the stiffer-strawed barleys now introduced stand up to more manuring than the older sorts.

If we are to have the optimum use of fertilizers we must breed races that will stand up to rich soil conditions. Tillage and suitable races will effect some increase of yield, but a further advance can be made by way of fertilizers.

Judging from the results of such manurial trials as are available, artificial soil conditions (cultivation and manuring) give maximum differences of about eight or more bushels per acre under ordinary farming conditions.

Researches on manurial trials carried out at Rothamsted (in conjunction with the Barley Research Committee of the Institute of Brewing and with the co-operation of a large number of growers) for a long succession of years have been very extensive.

I do not know the ultimate conclusion of this long series of investigations, but I should expect that it would more or less confirm that made by Munro and myself (1897) when we carried out similar investigations on Rothamsted material and which we summarized in the following words: 'Subject to good atmospheric conditions all the evidence points to sufficient but not excessive nitrogen supply and abundance of readily assimilable phosphates as the best manurial condition'.

We found that the plot on the Hoosfield, which had received

a moderate dressing of sulphate of ammonia combined with a full dressing of superphosphates and potash every year for the previous forty years, gave by far the best result: an average yield of 43½ bushels over the whole period: of better malting quality than that grown under any other set of manurial conditions: and much better both in respect of yield and quality than the average produce of barley in Great Britain during those years.

CHAPTER XV

MATURATION

MUNRO and I (1900) writing on various conditions affecting the quality of English malting barley made the following contribution to this subject:

The process of maturation being in itself so complex in character, it is not surprising that it is dependent very greatly upon conditions external to the plant. Its character will depend, first and foremost, on climate and season. It depends secondly and greatly on the natural character of the soil, and thirdly on its artificial conditions, that is to say, on the preparation, cultural and manurial, which it has been given.

If, on thin, poor soils in low conditions and in droughty seasons, barley 'goes off' and ceases to assimilate, that is to say, ripens, in the sense of being fit to harvest, without maturing, the grain is thin, hard and steely. Where, to take the reverse set of conditions, there is strong soil in too good condition and weather favouring vegetation rather than seed formation, the result will be too prolonged ripening, the straw 'holding out' instead of 'going off'.

It is, however, to harvesting conditions mainly that general over- or under-maturation is due. The former result never comes about by the will of the grower, but of late years there is a tendency to harvest barley earlier than when all the work of harvest was done by hand and when necessarily the operations were prolonged.

On some of the plots at Warminster it was customary to make paths by removing the young plants round the edges after the top-dressings had been applied. Even then it was necessary at harvest time to discard the outsides of the plots and remeasure the areas before weighing up the produce, because the plants at the extreme edges are very unduly developed owing to more air and soil space. The barley, especially of the outside drill, is invariably very strong and coarse. In 1899 we weighed up the grain and straw on a

certain length of one of the outside drills and, for comparison, of the two next inner drills at the time of cutting. We further left standing for a month, from August 9 to September 9 (during which time the weather was very variable), a further length of one outside drill and the two next inside drills, to see what would be the effect of such extreme over-maturation. The following figures show the character of the grain (1) at the time of cutting the crop, (2) after threshing, and (3) after a month's weathering.

TABLE XIII [1]

	Weight per 1,000 grains [1] (grammes)	Mealy grains per 100	Nitrogen per cent. of grain
1. *Grain rubbed out from barley as cut August* 9, 1899			
Outside rank	57·5	27	1·58
Next two ranks	51·7	36	1·37
2. *Grain harvested one week later and threshed November*, 1899			
Remainder of plot	51·7	67	1·32
3. *Weathered grains from adjoining area to* 1, *cut September* 9			
Outside rank	57·5	50	1·65 [2]
Next two ranks	51·7	86	1·39 [2]

[1] *Samples* 1, 2 *and* 3 *graded to equal weight per* 1,000 *grains, and results calculated to equal moisture content.*
[2] *The nitrogen content of the* fine flour *of these two samples was determined as follows: outside rank,* 1·50 *per cent.; two next ranks,* 1·19 *per cent. The different nitrogen content of the whole grain was, therefore, clearly not due to higher proportion of husk in the latter sample.*

The weight of both the grain and the straw on the one outside rank was nearly double that on both the two next

ranks together. The grain of the outside rank never really matured, although it was badly weathered; and it is a fact that barley grown on over-strong soils will not become mellow even with excessive weathering. This seems to point to the undesirability of very thin seeding, especially on strong soils.

Physiological Aspects of Maturation and Over-Maturation

We have already seen that during the vegetative period the plant absorbs and assimilates materials supplied by the soil and the atmosphere, and the absorbed matters of comparatively simple chemical composition are elaborated into matters of more complex structure. From carbonic acid and water there are ultimately formed carbohydrates; and similarly the nitrogenous matters, absorbed probably as nitrates, are ultimately found as proteids. This matter, which is chemically more complex, is at the same time built up into definite structures in the plant, that is to say, becomes fixed temporarily or permanently in location, as, for instance, starch granules or cell-walls. But that portion of the starch and cellulose and proteid matter which is stored in the seed is so stored for a special purpose, viz., to provide for the first needs of the growing embryo. As soon as the embryo begins to grow there sets in, so far as the reserve matter of the seed is concerned, a reverse process. The complex matter becomes more simple, and structures like starch granules and cell-walls break down. Carbohydrates become soluble and in part break up into carbonic acid and water. If the seed gives life to a complete plant, the whole of the reverse matter undergoes this breaking-down process. When the grain is merely malted, only the first stages take place.

Between the up-grade and the down-grade period there is ordinarily a resting stage, which will be long or short according to the location of the seed in relation to moisture and temperature. We say there is ordinarily a resting stage at this particular period, but there is no evidence, so far as we are aware, that this is an absolute necessity. Some grain which is unripe will grow under certain conditions, i.e. it must be partially dried before it is attempted to germinate it. There may be either no resting stage, or a very short one,

and that not at the usual period. But these are abnormal conditions. They do not arise in a state of nature, because the grains do not at that stage separate from the parent plant. When grain under cultivation is cut unripe it may grow very well, provided there are, first of all, drying conditions. But the grain is not only one but two stages from being 'fit' for malting purposes. Grain will grow when it will not malt. It has first to complete an intermediate stage, during which matter 'migrates' from the stem upwards to the seed, and within the seed, from the endosperm to the embryo. It will then have reached full size and all the material for malting be present in the grain, but the material will not be in the requisite condition. Something more is still required for complete maturation.

The last stage is that change in the structure of the endosperm which results in the grain becoming 'mellow'. It then shows a white, mealy-looking fracture when broken and, what is of importance, malts easily. Exactly what happens within the starch-containing cells has never yet been demonstrated. It is pretty certain that the change is not so much, if at all, in the starch granules as in the ground substance in which they are embedded. Starch is formed within granules of elaborated protoplasm called plastids, and in the endosperm of a barley grain remains embedded in a kind of 'matrix' of very composite character. It almost certainly is a change, either in the physical or in the chemical structure, or in both, of this 'matrix' which gives the difference between a mellow and a steely grain. To a considerable extent this alteration in structure may take place after the crop is cut provided the conditions are favourable, and indeed even after stacking.

There is a good deal of evidence to show that during the final stage of the process of maturation of an already ripe grain there is a slight loss of weight, and, if this is the case, it is the best proof that maturation is a post-ripening process. If the grain is very dry and remains so, nothing (as far as we know) happens, but if at this stage it takes up only a moderate amount of moisture, such as will be supplied by a few night dews whilst the crop lies in swath, and drying conditions alternate, then we have good reason to believe that the breaking-down process, which is, roughly speaking, the same

as that which goes on during the active growth of the seed, commences. Although this breaking down is much more complex than is there represented, the following equation illustrates what goes on:

nCH_2O	+	nO_2	=	nCO_2	+	$_nH_2O$
Carbohydrate		Oxygen		Carbonic acid		Water

One reason for believing that at this stage, without actual germination, this process begins is that we have proved a loss of carbonic acid to take place during what may be called the process of partial artificial maturation known as sweating. But the extent of this change and loss is normally insignificant. From a number of experiments made some time since, we estimated that with a barley containing 14·0 per cent. of water, which is rather under normal in this country, the carbonic acid expired on drying for twenty-four hours at a temperature of 100° F. was about ·02 per cent. of the weight of the grain. It is a fact well known to maltsters that grain which is very dry, such as some foreign barley containing only 11 or 12 per cent. of water, is not improved by further drying on a kiln. No maturation or mellowing takes place. English barley in ordinary seasons frequently contains after threshing 16 per cent. of water and sometimes more. Such grain is greatly improved as malting material by kiln-drying. Munro and I investigated at the time the question as to the precise conditions of moisture content and temperature under which the best results are obtained. A further very instructive line of research would be in respect of the changes, doubtless in the same direction, which take place under normal conditions in the stack.

The same process of maturation takes place with wheat, but there is this very material difference from the industrial point of view—that millers do not want mellow or soft wheats, or at any rate not more than a certain proportion of them—for although they give the whitest flour it is generally 'weak'. It is interesting, however, to note—as has been pointed out by Dr. Sidney Williamson, who has made a special study of this point in connection with wheat—that in this grain the transition from hard to soft, corresponding to that from steely to mellow in barley, can be often seen on a superficial

examination of the grain in the intermediate stage. Dr. Williamson has described wheat grain to Munro and myself in this stage as 'piebald'. The grain is, so to speak, speckled, the soft parts showing through the seed coats, and when such grains are cut the line of separation between the hard and soft parts is quite clearly defined across the starch-containing cells. Barley, at any rate the ordinary variety with adherent husk, does not give this appearance, but it would appear that the mellowing of the grain spreads from the neighbourhood of the cells underlying the furrow, that is from the median longitudinal axis, towards the outer part of the endosperm, which is the last part (particularly towards the apex) to become mellow. The difference between steely and mellow grain can be judged from its appearance by all who are familiar with malting barley, and can be further demonstrated in several ways, most easily by the well-known 'Korn Prüfer' or cutting instrument; also by the difference in translucency of the grains when seen by ordinary transmitted light. Steely grain is translucent, probably because of the continuity of the cell contents: mellow grain is opaque.

On photographing, by means of the X-rays, grains of steely barley, mellow barley and malted barley respectively, a rather striking set of appearances resulted. The photographs unfortunately cannot be reproduced by a block-printing process on account of their faintness, for, like other vegetable matter, barley grains oppose very slight resistance to the rays. Whilst, however, the 'radiograph' of the endosperm of steely grains appears quite uniform and structureless, that of mellow grains shows more or less numerous clefts or striations, as if the endosperm were split or discontinuous, and in malt the striations are so much more numerous as to amount to a network. It is probable that these are real air-spaces; at any rate it is difficult to account for the appearance otherwise, and if this is so, there must be many more of them than show in the 'radiographs', for only the spaces lying in planes passing through the source of light would be shown, and these would probably be but a small proportion of the whole. These 'striations' are much more numerous in barley grains originally steely, which have been experimentally subjected to a process of artificial maturation in imitation of the natural process, in so far as that, being a post-ripening process,

consists in alternate absorption of water and desiccation, as was suggested by W. Johannsen of Carlsberg, Copenhagen (1899).

If we were required to give the briefest possible definition of the process of maturation we should describe it as a 'commerce' of the ripe grain in water previous to germination and during the resting stage, that is, the alternate absorption and loss of water in such quantities as were not favourable to the starting of actual germination. This leads us to a consideration of the important subject of over-maturation.

Let is consider what happens to a grain under natural conditions, that is to say, to a grain which after full ripening falls to the ground. Obviously everything depends on its location in respect of the three conditions for germination, viz., water, air and warmth. Given all these, barley will germinate if fully ripe, even before separation from the parent plant. Grains which fall to the ground may alternately absorb moisture and become dry again without germinating, but all this 'commerce' of the seed in water is attended with chemical and physiological changes in the direction of germination. It is maturation under natural conditions, and, in the case of the wild-growing *Gramineae*, it is without doubt over-maturation to the point of decay as regards probably a very large proportion of the grains which are formed. Some seeds, like those of the *Cruciferae* (charlock is a well-known example), may be either undergoing this operation, or remain in the resting stage for a very long time, and may even be washed down into the subsoil, be retained there—probably for years—and then, on exposure to the air, germinate. The structure of the grain of the cultivated cereals, however, is quite different. The seed-corns are far less resistant, but it is worth noticing that barley seems to be provided with an envelope to the more starchy part of the endosperm, which affords greater protection than does that, for instance, of wheat. We refer to the aleuron layer immediately underlying the true seed coat. This, in wheat, consists of a single layer of cells, but in barley there are always two, and generally three or more, cells underlying one another.

This is by far the most persistent part of the endosperm. Its structure survives the earlier processes of germination long after that of the inner starch cells has completely

broken down. It seems clear that it is a function of this structure to preserve the inner endosperm from the undue effects of moisture in the stages of maturation and early germination; its much greater thickness in barley than in wheat may be due to the ordinarily longer resting stage of the seed within the grain of the former. This conjecture is strengthened by the fact which we have observed that the aleuron layer is frequently thicker in spring-sown corn than in the winter sorts.

There is room for much difference of opinion as to the precise degree of maturation desirable for malting barley. As a matter of fact in this climate the grower has little choice in the matter. The method of harvesting the crop with a 'binder' and setting in 'stooks' is not nearly so likely to give mellow grain as lying in swath. But a grower cannot afford to risk damage to the crop by delaying harvesting operations, so that it is almost wholly the character of the weather during the week before cutting and during the short period (often too short for good maturation) between cutting and harvesting which settles the matter. Weathered barley is generally mellow, though not always, but it loses weight by weathering and is seldom harvested free from grown corns, which conditions of course greatly depress its value.

Samples of barley are not very plentiful which will show more than 60 or 70 per cent. of 'mealy' fractures when cut, unless they are more or less weathered. But when grain of good colour and kindly appearance shows something like this percentage it will generally be found that the process of mellowing has commenced in almost all the grains, that is, the centre of the grain is mellow. Such barley will generally malt well, especially after sweating.

There is another respect in which the degree of maturation affects the quality of barley. The function possessed by certain constituents of the grain of converting the starch into soluble matters, called diastatic capacity, is, as maturation proceeds, diminished. This branch of physiological chemistry has been worked out by Dr. Horace Brown and Dr. G. Harris Morris (1890 and 1893) in a series of investigations which are recognized to be amongst the most original in conception and the most instructive, both in method and result, of any of their kind. They have shown the 'diastases' and allied substances

to be 'starvation products', that is, they are present in the proportion in which they are needed for the purposes they serve in rendering available the carbohydrates with which they are associated. Mellow grain does not need as much diastase to render the starch available as does steely grain, and accordingly we find that less is present. Barley may be overmatured to the extent of containing very little 'translocation diastase', the name given by Brown and Morris to the active agent in ungerminated barley; and Munro and I have found, from a great number of experiments, that the 'diastase of secretion' (i.e. that which the same authors show to be distinctive of germinated grain) is also lower after germinating mellow grain. Now, a certain minimum of 'diastatic capacity' is held to be necessary for different types of malt, and although this is ruled largely by malting processes it is also, as we have indicated, dependent on the character of the original grain.

Tests of Maturation

Without any knowledge of the conditions of cultivation and harvesting, a practised eye can see the evidence in a sample of grain which indicates premature, incomplete, or irregular maturation; although it must be said that it is sometimes possible to confuse with such indications the effects of the character of certain soils upon the appearance of the grain. Ill-matured grain is seldom of uniform colour; it is often smooth rather than wrinkled in the husk, but above all it is invariably 'steely', and when cut transversely shows a yellow, or flinty, rather than a white and mealy surface to the fracture.

Figs. 17 to 22 are micro-photographs of sections through (Figs. 17 and 18) half-ripe; (Figs. 19 and 20) coarse, large, ill-matured; and (Figs. 21 and 22), ripe, kindly, small grain respectively; and also there are shown still more magnified sections from the same part of the envelope of such grains. As between the half-ripe and the other grains the collapse of pericarp into a mere membrane, the compression of the testa or seed coat, and the marked development of the double and sometimes triple layer of aleuron cells, can be easily traced. As between the coarse and the kindly grain there may be noted the thicker husk and the

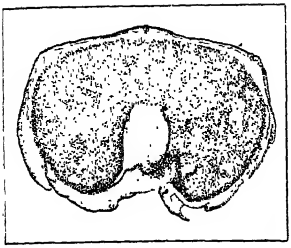


FIG. 17.

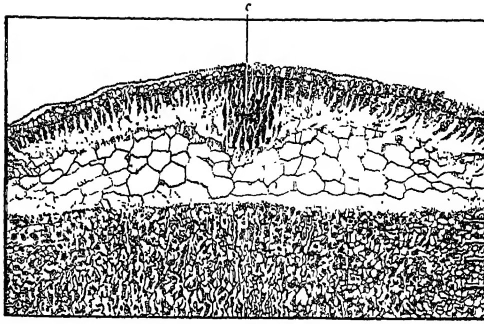


FIG. 18.

FIG. 17.—Median transverse section through about half-ripe grain (× 16).

FIG. 18.—Portion of same from dorsal side, opposite furrow (× 120).

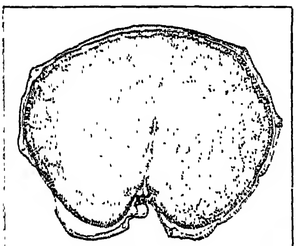


FIG. 19.

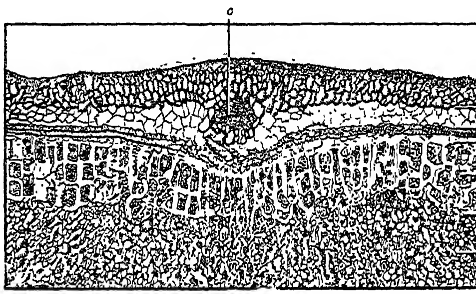


FIG. 20.

FIG. 19.—Median transverse section through large coarse grain, about 82 grammes per 1,000 corns (× 16).

FIG. 20.—Portion of same from dorsal side, opposite furrow (× 120).

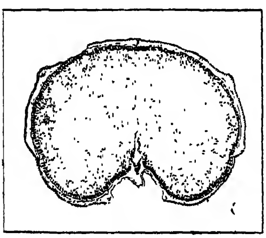


FIG. 21.

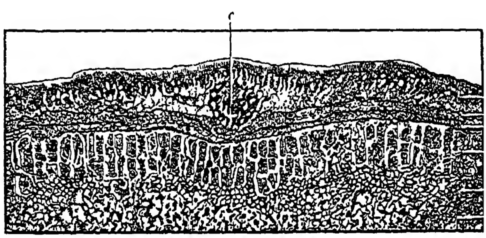


FIG. 22.

FIG. 21.—Median transverse section through small, well-matured grain, about 40 grammes per 1,000 corns (× 16).

FIG. 22.—Portion of same from dorsal side, opposite furrow (× 120).

---

a. Outer palea.
b. Inner palea.
c. Vascular bundle.
d. Pericarp.
e. Tegmen.
f. Aleurone cells.
g. Small polygonal starch and "reserve albumin" containing cells underlying aleurone.
h. Elongated starch-containing cells.

To face page 136

somewhat thicker aleuron layer of the former; also, by comparing the three sections in respect of the layer of starch-containing cells immediately underlying the aleuron layer, marked differences can be seen in the original photographs. This part of the grain has been described in full by a well-known investigator, J. Grüss,[1] who regards it as the special storehouse of 'reserve albumin'. It is apparently transitional, both in shape of cell and character of contents, between the inner much-elongated starch cells and the aleuron layer. Large, heavy, coarse grains have more 'reserve albumin' in the outer cells of the endosperm, and indeed more nitrogenous matter in every part of the seed. With such grain not only are the nitrogenous envelopes unduly thick, but the starch-containing cells, making up the larger part of the grain, have also a high content of nitrogenous matter.

Figs. 23 to 26 show the appearance of magnified images of the fractured surfaces of barley.

Fig. 26 is that of a steely grain and illustrates what appear to be the outlines of the starch-containing cell-walls of the endosperm, of which not a trace is to be seen in the similarly enlarged picture, Fig. 25, of a fully ripened and matured grain, which latter suggests that here the starch-containing cells have been ruptured, and a surface consisting wholly of starch granules exposed.

Figs. 23 and 24 show the surfaces of longitudinal fractures on the same scale, the fractures being made slightly on one side of the furrow of the grain to avoid a channel of non-starch-containing cells which lies between the bottom of the furrow and the central axis of the grain.

It might be supposed that the mode in which the fracture is made determines the difference in appearance, and that whilst the reticulated surface in Figs. 24 and 26 is due to the grain being rather split than cut, the floury look of the corresponding Figs. 23 and 25 is due to the cell-walls being crushed, with the effect of liberating starch granules and scattering them over the surface of the fracture. If, however, the cut surfaces of similar grains are pared down with a sharp instrument the difference in appearance of the surface is still very much the same. There is no doubt that what is

[1] *Wochenschrift für Brauerei*, 16, 532: Abstract in *Journal of Society of Chemical Industry*, xviii, p. 1143.

presented represents a distinct difference in the constituents of the grain.

Of course barley may be over-matured in the sense of suffering in colour, and even in vitality, from over-exposure to bad weather to such an extent as to render it unfit for malting. This condition is due to causes beyond control, and all that can be said is that if vitality is not seriously diminished much can be done by artificial drying to increase the germinating power, and that on the whole a limited amount of defect of colour is not so serious a condition as want of maturation. There have been seasons when there has been an abundance of grain in which both conditions have been in a sense combined; that is, when grain badly matured before cutting has been over-exposed between cutting and harvesting. Lack of vitality is here combined with bad colour and steeliness, and no artificial treatment in this case will yield good malting material.

Deficient maturation is the most serious prevalent defect of English barley, for whilst size of grain determines mainly the quantity of ultimate available material for use, maturation determines quality because it is the necessary condition for the success of the physiological operation of modification of the starch cells.

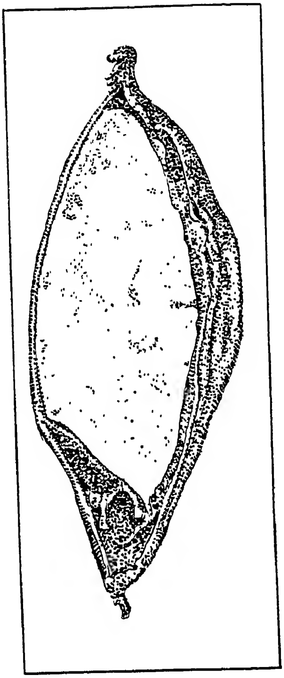


FIG. 23.—Well-matured barley. Surface of longitudinal fracture. (Magnified eight diameters.)

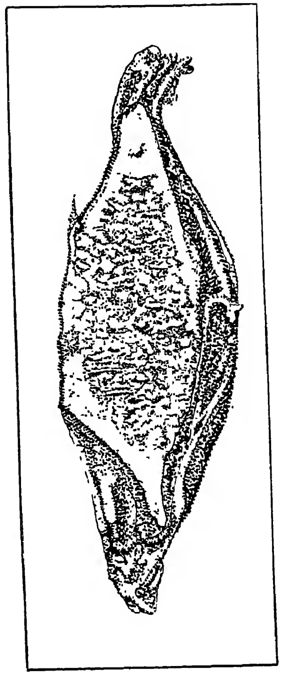


FIG. 24.—Imperfectly matured barley. Surface of longitudinal fracture. (Magnified eight diameters.)

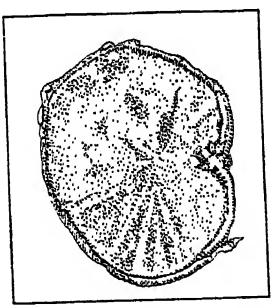


FIG 25.—Well-matured barley. Surface of transverse fracture. (Magnified eight diameters.)

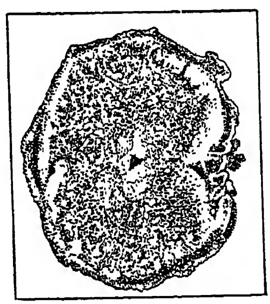


FIG. 26.—Imperfectly matured barley. Surface of transverse fracture. (Magnified eight diameters.)

To face page 138

CHAPTER XVI

DIFFERENTIAL RESPONSE OF RACES OF BARLEY TO ENVIRONMENTAL CONDITIONS

THE simplest definition of conditions for life which I have met with is 'correspondence to environment'. Unless a race is in harmony with its environment it will surely perish.

Every organism corresponds to environment and every race of every species, whether animal or vegetable, responds in a different manner. Farmers know that this applies just as much to different sorts of barley as it does to Southdown and Welsh Mountain sheep, or to Jersey and Highland cattle.

As between different species of *Hordeum* differential response may be taken for granted. There is also abundant evidence that this equally applies to aggregates which are classed as 'varieties' and 'sub-varieties'. In the case of cultivated barley a good illustration is afforded by those sub-varieties which are classed under the name H. *vulgare*. I have found that those sub-varieties which are in cultivation in India seldom survive for more than two or three generations when grown in the nursery at Warminster. Definite evidence of differential response in the case of races of the same sub-species has only of late years begun to accumulate.

Taking the whole area of cultivated barley in all the countries of the world, it is quite true to say that the environmental conditions are the main factors in determining total accumulation. These environmental conditions are for the most part beyond our control. For instance, it is doubtful if barley can be grown profitably in localities in any part of the world with an average rainfall of less than ten inches.

As between different races of barley differential response to environment is a response to soil fertility rather than to soil texture, and it is complicated by differential response to weather, to cultivation, to period of sowing, and, in fact, to all the variations external to the race.

No one race of barley is likely to suit all requirements, or indeed to be profitable to all growers, even within such a

limited area as that of Great Britain and Ireland, because of the differential response of races to extrinsic conditions. That does not mean, however, that we require a multiplicity of races. It is quite possible to have two or three, one or other of which will be suited to the conditions of most growers in Great Britain and Ireland, and the future race of barley breeders should endeavour to understand and appreciate the requirements of both growers and users of barley.

For many years I have accumulated evidence from my experiments that there is differential response of races of barley to soils in good or poor condition respectively. Going back many years, an experiment made with Archer and Plumage barleys in my nursery for a series of years showed that whilst Archer cropped better than Plumage on those parts of the nursery which, being in poor condition, gave yields corresponding to less than about five quarters per acre, Plumage, on the other hand, gave better yields, where the yields corresponded to six quarters or more. I also found that in exceptionally favourable seasons the differences in response to soil conditions as between these two races tended to disappear, and that they then yielded about equally both on the good and on the poor areas.

Archer and Plumage have now given way over wide areas to Spratt-Archer and Plumage-Archer, but I have some evidence that Spratt-Archer follows Archer and that Plumage-Archer follows Plumage in the same direction, though less definitely, and I believe this confirms the practice and experience of growers generally. Put briefly, it means that in respect of yield the Archer and Spratt-Archer type best withstands conditions adverse to plant growth; but that the Plumage and Plumage-Archer type profits most from good conditions.

There has been for some time a prevalent belief that Plumage-Archer barley is less suited to the soils of light texture than is Spratt-Archer; and probably a majority of Yorkshire farmers believe that Plumage is better suited to their type of land than either.

But we require more evidence on these points for different seasons and localities, and also for other races. The relative quality of different races must be taken into account, and I have no doubt that some races of barley stand high farming

better than others without the quality deteriorating, but so far we have insufficient evidence on these points.

Dr. F. G. Gregory and F. Crowther (1928) carried out at Rothamsted some hundreds of pot cultures of various barley races in an endeavour to elucidate the manner of their differential response to different chemical manures. Five well-known races of two-rowed barley were used for comparison, viz., Goldthorpe, Plumage, English Archer, Plumage-Archer and Spratt-Archer.[1]

There were eleven types of manuring, including deficiency of nitrogen, of phosphate and of potash. Dr. Gregory kindly allows me to reproduce one of his very numerous photographs (Fig. 27). This shows very clearly the effect of deficiency of potash in the soil on four different races of barley. Of these four races, Plumage and Plumage-Archer almost failed under severe restrictions of potash supply. With almost complete absence of potash the straw of these two races collapses at an early stage. On the other hand, English Archer and Spratt-Archer, under the same conditions, were very little affected.

The authors' conclusion from the data derived from these experiments was that there was established the existence of a differential response of races of barley to various types of manuring.

I am able to supply confirmation of their conclusion from the results of barley experiments at Warminster.

The impression I get from my own records is that the differential response is mainly to deficiencies of plant nutrients, qualified, no doubt (i.e. intensified or reduced), by atmospheric and all sorts of other environmental conditions.

An example of differential response is afforded by the totally different habit of growth of the mixed races which make up the aggregate of the greater part of the barley crops of British India, when seed grown in India is planted in this country.

I have received plants of barley, with roots attached quite four feet long, from agricultural stations in India, and have taken grain from them for seeding in my nursery.[2] I have

[1] The seed-corn for the last-named four races was supplied from, and grown at, the Warminster nursery.

[2] In India there is much variety in the root system as between different types of barley. Some barleys penetrate to depths varying from 4 ft. to 6 ft., with 'working depths' from a half to two-thirds of these figures. European barleys grown in India are said not to penetrate below about 4½ ft. and to have a 'working depth' of 2 to 2½ ft.

invariably failed to induce plants grown from grain imported from India to make an efficient root system. They develop roots about six inches long, obviously not sufficient in total weight to absorb the soil nutriment required to feed the plant. Fig. 28 illustrates the abundant root system of a single plant grown in India and the almost complete failure of a plant grown in the nursery at Warminster from the grain of one of its ears. This is not a case of failure due to non-supply of some plant nutrient, but it may be due to failure to produce a root system under a range of soil temperature alien to the inherited nature of the plant.

The following table illustrates differential response in races of similar morphological character:

TABLE XIV.—Warminster Barley Nursery, 1922

	Correlations between	
	20 plots of 'P.A. 1914'	20 plots of 'P.A. 1924'
No. of plants per plot and average weight per plant	−·13	+·81
No. of plants per plot and average weight per ear	−·12	+·81
No. of plants per plot and weight of ears per plot	+·01	+·85
No. of plants per plot and 'migration' .	−·14	+·75
Average weight per plant and 'migration'	+·26	+·72
Weight of straw per plot and 'migration'	−·11	+·69
Weight of ears per plot and 'migration'.	+·26	+·79
Average nitrogen content .	1·56 per cent.	1·58 per cent.
Average weight per 1,000 corns.	33·6 grammes	35·7 grammes

Differences of ·5 are significant.

The results of chequer-board nursery plots at Warminster, each year from 1912 to 1940 (generally twenty plots, each of eight races), in which the environment is only variable in respect of such soil heterogeneity as occurs within a few perches, have demonstrated that even these apparently slight

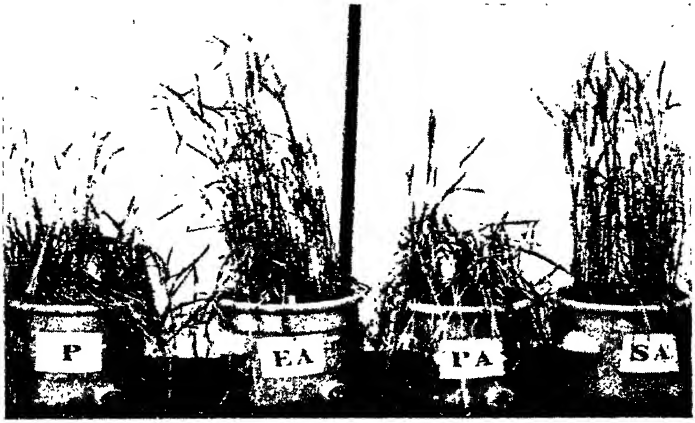


Fig. 27.—Differential response to potash restriction.

Fig. 28.—Racial response to environment.
1. H. *vulgare* grown in Ganges Valley.
2. Same H. *vulgare* grown at Warminster.

To face page 142

differences in environment produce 'differential response'. A summary of the average results of these chequer-board plots is given in Table A, p. 366.

In the half-drill strip experiment of 1922 another instance of 'differential response' was illustrated. There were twenty-seven parallel alternated half-drill strips of each of two races of barley, viz., 'Plumage-Archer 1914' and 'Plumage-Archer 1924', each originally single-plant cultures with the same ancestry. There were four 'manurings' across the half-drill strips with two controls of 'no manure' similarly across the strips, one at each end of the field, 324 plots in all.

The yields of dry grain of 'Plumage-Archer 1924' stated as a percentage of 'Plumage-Archer 1914' were as follows:

Plot	Per cent.	Maximum standard error * of any comparison
2 N+P+K	111·0	
5 N only	106·4	
3 P+K	98·0	3·5 per cent.
4 N+K	97·8	
1, 6 nil	94·3	

N = sulphate of ammonia. P = superphosphate.
K = kainit (14 per cent. potash).

* *The standard error above quoted is derived from the weights of total raw produce on each of the plots. From many other experiments it may be accepted that the standard error of raw produce is higher than that of the corresponding dry grain, which was not determined.*

The evidence is conclusive that there was 'differential response' in this experiment. N was in the form of sulphate of ammonia and in this particular environment 'Plumage-Archer 1924' responded better than did 'Plumage-Archer 1914' to this manuring, both when it was combined with phosphate and potash and when it was applied alone. In 1923 a similar experiment under other weather conditions on the same area gave different, but less significant, relative responses as between the two same races of barley.

It is evident that no two races of a cereal respond quite

equally to the same environment, and that, as between races, relative yields on unit area, whether of total produce or of seed, are influenced by all the environmental effects and by their interactions. This seems indeed to be a corollary to the doctrine that the survival of any one species has been mainly dependent on natural selection. It is illustrated by innumerable facts and may be summarized by the aphorism 'What is food for one race may be, more or less, poison for another race of the same species'. As an example: Plumage-Archer since 1927 has been included amongst about forty races tested for yield at twenty experimental stations in Canada. At only one station, Fort Vermilion, Alberta, which is the most northerly station of all (latitude 58° N.), with a very short growing period, viz., about 100 days, has it given fairly consistently the highest yields.

A large number of observations, preferably on the field scale, will be required before we can hope to disentangle the environmental effects, to which manures are only a contribution, in order to enable us to apply the knowledge so gained to the breeding of races better adapted than existing ones to specified conditions.

In the conduct of interpretation of comparative trials of old and new races, whilst fully recognizing the existence of these differential responses, we can at present only proceed by the method of sufficient replication and repetition of comparisons, in space and time, under various environments, and by treatment of the results so obtained by statistical methods in order to evaluate their significance. Furthermore, environmental effects on the quality, as distinct from the yield, of the produce must be taken into account.

It is quite safe to say that for every conceivable set of environmental conditions and for every species of farm plant there is a race which would be more productive in the long run than any other race. The task of the plant breeder is to relate the race to the environment in respect of yield and quality.

We are only at present at the very beginning of the investigation of this very complex problem of the differential response of races of any one species and we are not able as yet to draw conclusions of practical application, although we shall, no doubt, ultimately be able to do so.

CHAPTER XVII

OLD CUSTOMS AND CHANGES RELATING TO BARLEY AND MALT

I HAVE no intention of relating the methods and process of the art of malting in this volume. This has been done very efficiently and concisely by my old friend and late pupil, Mr. H. M. Lancaster (1936). But before I expound the experimental side of my work I should like to relate some changes in connection with barley and malt usages which have occurred within my memory.

I shall commence by giving a few personal reminiscences of still earlier years.

I have recently unearthed an old 'Bought Barley' book which was kept by my late father-in-law, whose business I entered in 1878. From the records I observe that in 1857 one of the entries is that of a purchase of barley from my father (who at that time was farming at Heytesbury, Wilts) at 44s. a quarter. The deal was no doubt done in the Market Place at Warminster. The Market Place was the main street of the town, along which every Saturday, in the open air and in all weathers, stood sacks of grain in a double row, as had been the custom for hundreds of years. All the grain to be sold was brought in on farmers' wagons and put into one or other of the stores, which were at that time attached to each of six or seven inns in the Market Place. The 'Bailiff' of the market took from the store one sack from each bulk, dipped out a quarter of a peck into a brass bowl (how well I remember seeing him do it), as was the customary right of the lord of the manor, and then set down the same sack on some wheat straw previously laid down for 'bedding' by the carters, whose perquisite it was to bring in as much of the farmers' straw on the top of their loads as was necessary for this purpose and subsequently to sell the same. Then on Saturday mornings dealings went on from about eleven to one o'clock, when all the farmers sat down to dinner at the 'ordinary', a function now, alas, in so many old market towns

sadly depleted. The chairmanship of each 'market ordinary' was a coveted office, and the discussions over the gin-and-water which followed in the afternoons laid the foundation for all the Chambers of Agriculture and Farmers' Unions which were established later. But the farmer did not pay for the gin-and-water. Before that stage was reached the local millers, maltsters and corn chandlers, if they had not dined with the farmers, came in with banknotes stuffed into their top-hats to pay for what they had bought. They already had inspected, if they so wished, the bulks of grain where they were stored, so there were no disputes as to whether the bulk was inferior to the 'market sack'; there were no guarantees about artificial drying; no arbitrations; no allowances! But to revert to the gin-and-water. When the amount due was agreed, the buyer deducted sixpence for every ten quarters of grain he had paid for and this was spent there and then. Such were the good old times. They lasted well within my recollection, but are now for the most part bygones. William Cobbett, yeoman farmer, plant breeder, radical journalist and farm labourer's friend, as he was, gives a truly delightful account of these market customs in *Rural Rides* (1885), with special references to Warminster, in his day the largest barley market in the West of England, and one of the few in which no 'bag samples' were allowed.

> *Sixty years ago there were thirty-nine malt-houses in Warminster. Now there is only one, and not nearly enough barley within reach of that one.*

But before 1886 these customs had begun to fall into decay. Corn exchanges had been built to replace the old street markets, paper-bag samples were in full use and methods of selling and buying barley (which had been fairly constant for a century or more) changed rapidly. These changes were in a great measure due to railway transit replacing the farmer's wagon. To-day all farmers sell their barley at farms, to be collected by the dealers: none will deliver to railway stations. With the advent of tractors farmers have fewer horses to spare for carting grain. We know of course that road transport of grain has largely increased and that the farm wagon has been completely superseded by lorries. This is partly a consequence of our present rage for speed.

THE MALT TAX

A duty on malt was first imposed in England in the year 1697, at the rate of $6\frac{16}{21}$d. per bushel, which varied afterwards at intervals, until in 1856 it rose to 2s. $8\frac{11}{12}$d. per bushel. It remained at 21s. $8\frac{1}{2}$d. per imperial quarter until the abolition of the duty by Mr. Gladstone in 1880, in favour of (at first) 6s. 3d. per barrel of wort of 1057° gravity (commonly called 20-lb. beer), only a little above the average strength at that time. One effect of this change was to establish the 'free mash tun' and to permit the use of 'flakes' as a substitute for malt, in addition to sugar, which was previously allowed.

In Scotland malt was taxed uninterruptedly from the year 1713, *and in Ireland from* 1785 *at varying rates. In* 1823, *however, the duty was fixed at* 2*s.* 7*d. per bushel for the United Kingdom, and to this, in* 1840, 5 *per cent. was added, whilst during the Crimean War the duty was temporarily increased to* 4*s. per bushel. Malt made from 'bigg' or 'bere' in Scotland and Ireland was charged at a lower duty.*[1]

Malt tax was in practice charged on each imperial bushel of barley, i.e. by volume, and the Excise was entitled to measure the volume either before or after it was steeped, a given volume of wet grain being taken as equivalent to a bushel of dry grain, and the custom of the Excise was to 'gauge' the wet grain in the 'couch'. When very light grain was steeped, the volume after steeping was greater than that of heavy grain, and so the duty was actually higher than on heavy grain.

I have in my possession copy of a Petition addressed to the Commissioners of Excise for Great Britain and Ireland, drawn up at Weyhill, Hants, the 13th and 14th October, 1845, and signed by 179 maltsters, representing the counties of Hants, Oxon, Surrey, Wilts, Somerset, Dorset and Gloucester, as a protest against prosecutions made under 5th Section of 1st Victoria, Cap. 49, by reason of (to use their own words) 'the uncertain gauges of officers'.

I well remember an agitation amongst maltsters on this point. In 1876, and shortly afterwards, in 1877 (or 1878), a regulation came into effect under which a procedure was

[1] *Brewers' Almanack*, 1917, p. 130.

adopted which permitted of the duty being charged on the dry grain, and I believe was variable with the weight per bushel. One condition was that after the grain had been 'gauged', i.e. measured in the cistern, the cistern should be covered and locked, the Excise officer taking the key away with him. No doubt some relics of these covers and locks may be still found in some of the old maltings.

Use of English and Foreign Barley

It was an opinion widely held that the repeal of the Malt Tax injuriously affected the interests of the British barley grower, mainly by encouraging the use of cheaper foreign barley for malting. It was thought that home-grown grain was displaced thereby to the extent to which the use of the foreign article had increased, and in consequence of this competition the average price of British barley had been considerably lowered.

If the average prices and the acreage under wheat are compared with the same figures for barley over periods of fifteen years before and after the repeal of the Malt Tax, the following facts are obtained. For the fifteen years, 1866 to 1880, the mean of the *Gazette* yearly averages was 52s. 3d. per quarter for wheat and 38s. 3d. per quarter for barley. During the same period the acreage of the United Kingdom under wheat somewhat declined, whilst that under barley remained nearly stationary.

The fifteen-year period 1881 to 1895 was that of the great fall in prices of grain of all descriptions. Yet considering the following figures it is evident that barley suffered less than wheat.

Table XV

	Wheat	Barley
Average, 1866–80 . . .	52s. 3d.	38s. 3d.
Average, 1881–95 . . .	33s. 2d.	27s. 9d.
Under previous period . .	36½ per cent.	27½ per cent.
Acreage, United Kingdom, 1867	3,640,051	2,440,242
,, ,, ,, 1881	2.967,059	2,662,927
,, ,, ,, 1895	1,456,042	2,346,367

It appears that since the repeal of the duty barley had fallen in price less than wheat, and that the acreage under barley was nearly the same in 1895 as in 1867, whilst the wheat acreage in the same period diminished to less than one-half. Increased foreign competition and the general fall in prices affected wheat cultivation in the United Kingdom more seriously than did the same conditions plus the effects of the repeal of the malt duty affect barley; and the maltster is a better customer to the English corn grower than is the miller, although, we may add in passing, he is from the necessities of his business a somewhat more exacting one in respect of quality. From all the data available it appears that the quality of home-grown barley malted in the United Kingdom, taking one year with another, was not decreased, but was very little (if any) less than it was before the repeal of the Malt Tax in 1880.

It is unfortunate that there are no official records of the quantities and kinds of imported barley which have been used for brewing in this country, and that for our information as to this we have to depend on either individual experience and records, or from what we can infer from official returns of quantities and declared values of imports from various countries.

Apart from the fact that foreign barley possesses some qualities in relation to the malting and brewing processes which are frequently lacking in our native barley, it became necessary to use it whenever, owing to bad harvest conditions, there was a shortage of sound barley in the country. I have no doubt that these bad harvests were more frequent in the eighties and nineties of last century than they have been since. From *Records of the Seasons*, compiled by a scholarly Wiltshire farmer, T. H. Baker (1911), from systematic notes of his own and of two ancestors between 1819 and 1911, it would appear that in 16 out of 21 years (1879–99) harvests were later than for the average of all the years preceding and following, and late harvests of course mean 'weathered' barley.

I cannot recall any other such bad harvest as that of 1879. In that year much barley was lying in the fields in November, fit only for pig-food, and from my old 'Bought Barley' book, to which I have already referred, I see that 75 per cent. of the barley we steeped in 1879–80 was foreign—mostly Danish

—imported in small schooner cargoes of about 1,000 quarters each to Weymouth; with some French from the Saumur district; and a little from the Saale district, now part of Czechoslovakia. The character of the small quantity of native barley steeped in this season may be judged by the fact that the prices of different parcels ranged between 52s. and 25s. per quarter, the latter no doubt discoloured but still possible malting material.

All this imported barley was two-rowed (H. *distichum*) then, and afterwards, often called 'Chevalier' to distinguish it from the thinner six-rowed (H. *vulgare* and H. *hexastichum*), although, strictly speaking, Chevalier is the name of one variety of H. *distichum*. Under the old Malt Tax it was very seldom profitable to a maltster to steep thin foreign six-rowed barley, although I believe that a few brewers in Scotland had already begun to use some of this class of barley, mainly from Smyrna.

The general characteristic of foreign two-rowed barley, as distinguished from English two-rowed barley, is its better condition, i.e. lower proportion of contained moisture. Only in the case of a few countries with exceptional climatic conditions, conducing to full, even, and not too rapid maturing of the grain, does foreign two-rowed barley generally surpass the best English growth in other respects than that of dryness. Apart from dryness, and speaking generally, it may be said that the importation of Chevalier foreign barley depended largely on price as related to English; and in respect of the better qualities the extent of the importation depended mainly, as we have already seen, on the available supply of really fine English samples.

From the Board of Trade returns for the five years 1881–85 I estimate that the average use of imported barley for brewing was about 25 per cent., mainly of Chevalier type, from Denmark, France and mid-European countries.

After about 1886 the use of six-rowed barley (H. *hexastichum*) increased, and up to the early nineties all the imports of this barley were from Mediterranean ports, principally from Smyrna.

Hordeum *hexastichum* is of the same sub-species as our own winter barley, but there are many different varieties of it and the growth of no two countries is alike. It comes

chiefly from the Levant, Algeria, California, Chile and the Danubian districts. The better sorts of this class of foreign barley make malt which brewers prefer for two reasons, apart from relative price, which is the main determining. factor. The first is that, containing about 10 per cent. more of insoluble matter, husk, etc., than Chevalier barley-malt, it can be much more closely crushed and yet give good drainage in the mash-tun. Secondly, it is generally modified in the malting process in a somewhat different manner from English barley and yields an extract which, though less in quantity, is in some important respects better in quality than that given by the lower qualities of English two-rowed barley in most seasons.

Since 1886 Californian and Chilian Chevalier, also two-rowed Danish and most European barleys, have been imported in limited quantities from time to time; but it was soon discovered that the six-rowed Californian 'Brewing Barley' gave better value for money. Between 1890 and 1900 this barley came rapidly to the front and for many years California has provided us in the aggregate with more barley for brewing than all the rest of the barley-exporting countries put together, and nearly all of it has been of various six-rowed races. One reason for its popularity is, without doubt, its uniformity of character from year to year. Climatic conditions in California are less variable than in most other barley-growing countries and until some enterprising plant breeders and others began 'tinkering' with the grain and distributing new 'breeds' the racial character was also uniform. It was all the progeny of Mediterranean barley taken there by early Spanish settlers.

But in California, as in England, growers cannot be expected to think first of the interests of the brewers. They will grow what pays them best, and there is no doubt that some of the new races of six-rowed barley which have been distributed in California during the past fifty-odd years have been more profitable to growers than the old 'Bay Brewing' type, mainly because they give higher yields and are just as good for feeding purposes, for which one-half, or more, of the Californian crop is utilized.

We must remember that, within limits, environment has more effect than racial character on the quality of the grain

of any cereal. So it comes about that all Californian barley, be it 'Bay Brewing', or 'Mariout', or 'Atlas', or 'Vaughn', or any other type or race, has a certain similarity of character. Incidentally, I must add here two remarks. First, that the above holds good only within limits. There are certain high-yielding races of barley, like that known as 'Trebi' in other States of America, which would almost certainly defeat even the favourable environment of California and produce a type of grain which no British brewer wants. Secondly, it may turn out that in future years conditions will prevent anything like as large an export of Californian barley as there has been in recent years.

The use of increasing proportions of six-rowed foreign barley in this country is without doubt the most drastic of the changes which have taken place in the last fifty years.

CHAPTER XVIII

NOTES ON SOME INDIVIDUAL FOREIGN AND EMPIRE BARLEYS

California

Coast (also known as 'Bay Brewing') was before 1910 the only sort of barley of any importance in the State of California. The barley was originally all *vulgare*, vars. *pallidum* Al. and *coerulescens* Al. (like Spanish, from which it is no doubt descended in a more or less modified form). It is a six-rowed, narrow-eared barley with smooth rachilla. It is now invariably mixed in commercial bulks with 'Mariout', var. *parallelum*, Kcke.

Commercial Mariout is of many distinct races, some having smooth and some rough rachillae. Originally there were two broadly different aggregates, viz., 'Californian Mariout' and 'Club Mariout', both six-rowed, narrow-eared barleys, with a rough and smooth rachilla respectively. These two aggregates are now generally found mixed, but in commercial samples those with smooth rachillae very largely predominate. Both of these aggregates were no doubt originally descended from small bulks received from Lower Egypt, where, although those with smooth rachillae predominate, some with rough rachillae are also found. Egyptian barleys generally have smooth rachillae and are mainly of the sub-species *vulgare*, var. *pallidum*, more or less resembling the Coast type of Californian barley. The grains found in mummy-cases are generally of this type, but in a recent prehistoric (predynastic) excavation by Sir Flinders Petrie some grains of *hexastichum* were found. Club Mariout accounts for about 15 per cent. of the barley acreage; it has a limited use for malting. The botanical classification of Mariout is difficult to define.

Atlas, a six-rowed, narrow-eared barley, with smooth rachilla, proved to be the best of several hundred 'pure line'

selections made from 'Coast' in 1917. It has a good stiff straw and ripens early. It covers about 80 per cent. of the malting-barley area.

Chile

Chilian Brewing is a mixture (in all commercial bulks) of many races of sub-species *hexastichum* and *vulgare*: the former predominating, with occasional small admixture of *distichum* (Chevalier). The rachilla of all these types is almost invariably smooth, but occasional grains with rough rachillae occur.

Australia

Cape (so called) six-rowed barley is of variable quality and there is now only quite a small amount grown.

Australian Chevalier, a narrow-eared, two-rowed barley, with smooth rachilla, grown in W. Australia, is of better quality than that grown in any other part of Australia.

Pryor's Chevalier.—The origin of this barley is interesting and was related to me by Mr. William Barrett, senior partner of Barrett Bros. & Burston & Company, Proprietary Limited, the largest firm of sale maltsters in Australia. About thirty years ago an old Scotch farmer named Pryor brought a load of barley to one of their malt-houses. The barley looked entirely different from any they had seen before and they were anxious to learn all there was to know about it, but the farmer obdurately refused to tell them anything about its origin. However, they bought the barley and sold it for seed to several farmers in the neighbourhood. It spread very rapidly and almost completely replaced the older sort, Duckbill (or Spratt). I have grown small plots of Pryor in the nursery at Warminster and found it to have a shorter growing period than any other two-rowed barley. This is probably one reason for its popularity in Australia. Mr. Barrett tells me that owing to its quick-growing habit it escapes what he calls 'caterpillar' attacks, which in some districts of Australia are apt to be devastating, like the gout-fly in this country; also that season after season quality and regularity fluctuate less than with any other type grown in the country.

Just over ten years ago I sent out samples of Spratt-Archer,

Plumage-Archer and Golden Archer to Australia and all these races are now grown in some districts, but they have not, I believe, spread widely so far. I had a report from Mr. Barrett of the results of the harvest of 1930. The net result was that these races were found to be quite useful in some of the barley districts in S. Australia, but in other districts Pryor's Chevalier continued to give the best results. Growth and parasitic conditions in Australia are sure to be variable.

The analyses of the samples of these three races which I received from Messrs. Barrett are as follows:

	N. *per cent. dry barley*	*Weight per* 1,000 *corns dry (grammes)*
Plumage-Archer .	1·31	40·6
Spratt-Archer .	1·26	33·8
Golden Archer .	1·36	38·0

India

Some years ago very useful barleys were shipped from the ports of Calcutta, Karachi and Bombay to this country, but of late years prices have been generally higher than those of some other exporting countries.

Indian barley is no doubt a mixture of indigenous races, grown under all sorts of varied soil and climatic conditions. I believe that Indian barley has remained about the same since it started from some wild type about 10,000 generations ago, and that this wild type must have been quite different from any of the progenitor races of our European and N. African types, of which there have been perhaps only about 3,000 generations. This may account for a difference in habit which is difficult to eradicate. Most of the barley is grown in the northern parts of India, the United Provinces and the Punjab. The United Provinces has the largest acreage.

Indian (and Mesopotamian) barleys generally mature very

feebly in this country. The progeny of the great majority of the plants when grown in Great Britain have a very rudimentary root system and die out in the second or third generation. A few however survive, and in exceptional cases give rise to vigorous races.

New Zealand

This country produces a far smaller quantity of barley per head of its population than either England, Australia or Canada, although the return per acre to the grower is more than twice as much as in either Australia or Canada. The land is well adapted for growing suitable malting barley, but probably dairy produce and meat are more profitable to the farmer. Only two-rowed barleys are grown and consist almost entirely of one variety, viz., 'Duckbill'. I recommended both Spratt-Archer and Plumage-Archer as suitable races for the climate and they are spreading, though not as rapidly as might be expected.

Canada

*O.A.C.*21, a six-rowed, narrow-eared barley, with smooth rachilla (H. *vulgare*), has spread all over the Dominion and no doubt the commercial grades consist largely of this race. The original selection was made at the Ontario Agricultural College (hence its name) from a stock which came from Russia in 1881. It has been very fully tested all over the Dominion since 1910 and has generally given higher yields than any other race.

Trebi, a more recent six-rowed, narrow-eared barley, with smooth rachilla, is very different in character from 'O.A.C.21'. It was selected from some Asiatic Turkish barley which came to one of the United States experiment stations in 1905. It is a heavy cropper and has a wide range of adaptation. Wherever it is grown it seems to have lower nitrogen content than 'O.A.C.21' when grown under similar conditions, but 'O.A.C.21' is preferred by Canadian brewers. Both these races have been grown in the Warminster nursery in alternate plots.

Trebi barley came originally from Trebizond (a Caucasian district).

EGYPT [1]

Mariout, a six-rowed, narrow-eared race, is grown in Northern Egypt and is quite useful malting material.

'Beheri' is really a district and not a name for a type of barley. The barley is grown within the Delta of the Nile.

[1] It is possible that the barley which is grown in each district of Egypt is just what has survived from prehistoric times. On the whole, if seed goes from one district to another the difference in the character of the seed would be mainly due to soil and climate. I have grown some Egyptian barleys in the cage at Warminster and have observed no botanical differences.

PART II

EXPERIMENT

Note.—This part gives, in chronological sequence, an account of the author's experimental work in connection with barley breeding and of the deductions he drew. Descriptions of the methods employed are included. Some of the results have been published from time to time, but only those still of value or likely to be helpful to the farmer and plant breeder have been collected here.

Much of the work was done in 1900 or earlier and some of it may now be out of date. The original terminology and tenses have been largely retained.

CHAPTER XIX

THE WARMINSTER EXPERIMENTAL STATION

The area of land on which the cultivations are conducted is now about four acres, of which one-sixth of an acre is occupied by a bird-proof wire structure, first erected in 1902 and extended to its present dimensions in 1904. The space occupied by the cage is cultivated entirely by hand labour.

The soil is sandy loam situated on the Upper Greensand underlying the Chalk. This formation usually occurs as a narrow belt surrounding the larger Chalk formations in England. At the head of the Wylye Valley, near Warminster, it forms a 'tongue' between chalk hills, which is fairly flat in contour. This particular field is level and the sandy upper soil rests to a depth of about ten to twelve inches on a sub-soil of loose sandstone which passes gradually into sandstone rock, affording good, but not too rapid, drainage.

The following is an analysis of the soil:

Mechanical Analysis of Fine Earth

Coarse sand	67·8
Fine sand	11·1
Clay (so called) ignited	15·0
Vegetable matter	6·1
	100·0

Chemical Analysis

Vegetable matter	6·07
Sand and clay insoluble in acid	87·95
Carbonate of lime	1·65
Oxide of iron and alumina	3·58
Magnesia	0·29
Phosphoric acid	0·30
Potash	0·31
	100·15
Total nitrogen	0·219

This is perhaps one of the most generally useful types of soil we have. In good seasons it produces grain of excellent quality and over-average yield, and it is much richer and deeper than many of the deposits resting on the Chalk which are the typical soils of the South and East of England.

The land was probably under permanent pasture up to about 1860. From then on up to about 1880 it was occupied by a nurseryman and afterwards, until 1892, was under various field crops. Since that time it has been chiefly used for various manurial experiments with potatoes and barley, and from 1919 to date the greater part of the field has been used for half-drill strip trials of barley. In 1936 the part of the field not utilized for these particular experiments was planted with mangel, after having been under barley for several years in succession. The nursery and eastern part of the field have been under barley for 34 out of 41 years since 1900.

Parts of the field are unfortunately infested with Small Bindweed (*Convolvulus arvensis*), also with patches of Horsetail (*Equisetum arvense*), which necessitates occasional fallowing or cleaning of crops.

With the exception of the classical Hoosfield, at Rothamsted, this area has probably grown more crops of barley than any other during the past forty years. As at Rothamsted, on fully manured plots, the average produce per acre has probably been equal to the average on similar soils under ordinary cultivation. The manuring is varied from year to year and is designed to promote a fair yield without 'lodging' of the crops.

The field is probably more uniform than the average of cultivated areas in England used for similar investigations, but even so there is considerable variability due to both natural and artificial causes, which must be allowed for in considering results obtained.

Barley of one sort or another can, of course, be grown under almost any soil conditions. Amongst the collections of plants, comprising several hundreds, which have been grown at this station for many years there are barleys grown originally as far North as Iceland and as far South as Abyssinia.

Preliminary Experiments

The first experiments with barley in the field were carried out in 1895 on a part of this area. I was at that time making investigations in collaboration with Munro. We started single plant cultures of various established races of barley on small plots with a total area of a few perches.

In 1895 we experimented with 'Hallett's Pedigree' obtained from the original grower. In 1896 the seed used was of the 'Goldthorpe' variety, selected for the purpose on account of the fact that this particular barley appeared to be more easily affected than most others by the various conditions which determine quality. In both cases the seed was kiln-dried before planting.

Goldthorpes and Chevaliers were grown side by side for six consecutive years with a view to making comparisons. There was an area of one-sixteenth of an acre for each condition of manuring, excluding a surrounding margin to the whole area, which was cut and removed before the produce of the measured areas and served the object of securing the absence of the effect of 'outsides' on the measured areas. The individual plots were divided and duplicated in order more fully to secure uniformity of soil.

These experiments were exclusively designed to throw light on the respective malting quality of varieties of barley under different conditions of cultivation without relation to relative productivity.

Naturally at so early a period of experimental work in the field we had not sufficient data to warrant any conclusive evidence on the trials made. We therefore sought the co-operation of Sir John Lawes and Sir Henry Gilbert in the attempt to relate quality of barley with cultural conditions. They generously placed at our disposal all their Rothamsted barley records and provided us with portions of the many hundreds of samples preserved at Rothamsted.

Thus began a long series of experiments which culminated in the publication of 'Manurial Conditions affecting the Malting Quality of Barley' (1897), and 'Various Conditions affecting the Malting Quality of Barley' (1900) in the *Journal of the Royal Agricultural Society of England.*

CHAPTER XX

INVESTIGATIONS ON ROTHAMSTED (HOOSFIELD) BARLEY

INTRODUCTORY

THE Rothamsted station was started in 1843 by John Bennett Lawes (and maintained up to 1900 in partnership with Joseph Henry Gilbert) mainly with the object of investigating the comparative effects of various artificial manures on farm crops. The general scheme was to mark out plots in several fields and to give to each plot year after year the same quantity of the same kind of manure. Although repetition year after year on the same areas showed clearly the wide extent of seasonal effects and gave valuable information on the subject of soil exhaustion, there was no replication of similarly treated plots on different areas with a view to demonstrating the effects on the yield and quality of crops due to soil heterogeneity other than that due to manuring.

Two series of barley experiments had been conducted at Rothamsted, (1) the Hoosfield Manurial Plots, and (2) the Agdell Field Four-Course Rotation Plots. We shall deal in this chapter with the experiments made on the Hoosfield plots in the cultivation of barley with different manures, commenced at Rothamsted in 1852. With a very few unimportant exceptions, the manurial treatment of the respective plots was the same for every year during a period of forty-four years. These experiments were made in order to determine the effects of the various different manures applied on the maintenance of fertility of the soil on the several plots as indicated by the ratio of grain to straw produced in successive years. Gilbert had pointed out how greatly the malting quality of produce of the differently manured plots had depended on atmospheric conditions affecting ripening. At the same time, the results on these plots show certain very definite differences in size of grain and maturation due to manurial conditions, and Munro and I considered in detail the evidence as afforded

by these plots, available both from the published records of the experiments and also from the samples and information supplied to us.

Malting Quality of Barley grown on the Hoosfield Plots

If the presence in the soil of, on the one hand, full, or on the other hand restricted, supplies of the various kinds of plant food which manures contain has any definite effect on the quality of the grain, these plots unquestionably afford evidence of an incomparably more complete nature than can be obtained from any other source, for nowhere else have the same soil areas received, for anything approaching such a period, continuous similar treatment, with the results of that treatment continuously recorded.

The different conditions of manuring which are illustrated by these barley plots, and the nature of the recorded data available for judging of the effect of these conditions on the quality of the grain, stated briefly, are as follows:

1. *The Different Manurial Conditions*

Plot 1–O has received no manure for forty-four years, and the yield of grain fell to 13 bushels per acre in 1895. Here is the result of general exhaustion; the relative exhaustion being apparently, from the results of the other plots, greatest in respect of nitrogen, next in respect of phosphoric acid, and least in respect of potash. The whole series of experiments shows that these are the only three elements of plant food the exhaustion and supply of which need be considered, at any rate on the Rothamsted soil.

Plot 2–O has received every year $3\frac{1}{2}$ cwts. per acre of superphosphate only, and yielded $16\frac{7}{8}$ bushels per acre in 1895, showing the effect of exhaustion of nitrogen, and possibly of potash, with full supply of phosphoric acid.

Plot 3–O has received 200 lbs. of potash salts and other salts of the alkalies,[1] and yielded $13\frac{1}{4}$ bushels per acre in 1895, showing effect of exhaustion of nitrogen and phosphoric acid, with full supply of potash, which supply it is to be noted

[1] All the '3' and '4' plots have received soda and magnesia salts yearly, in addition to potash.

has not increased the yield above that of the unmanured plot.

Plot 4–O has received superphosphate and potash salts (the combined dressing of Plots 2–O and 3–O [1]), and the yield was 16¼ bushels per acre in 1895, showing results of exhaustion of nitrogen with full mineral supply, the yield being no more than with superphosphate alone, again showing that addition of potash was without effect on quantity of produce.

The plots of the 'O' series, then (1–O, 2–O, 3–O and 4–O), have none of them received nitrogen in manures for forty-four years, and show the effects of supply or exhaustion of mineral plant foods in the absence of renewed nitrogen supply.

Plot 1–A has received nitrogen in the form of 200 lbs. ammonia salts only, every year, and yielded 22 bushels per acre in 1895, showing effect of exhaustion of phosphoric acid and potash.

Plot 2–A has received the same ammonia salts as 1–A, and 3½ cwts. of superphosphate, and yielded 29 bushels per acre in 1895, showing effect of exhaustion of potash with full supply nitrogen and phosphoric acid.

Plot 3–A has received the same ammonia salts as 1–A and 200 lbs. potash, and yielded 28 bushels per acre in 1895, showing effects of exhaustion of phosphoric acid with full supply of nitrogen and potash.

Plot 4–A has received the same ammonia salts as 1–A with superphosphate and potash in the same quantities respectively as 2–A and 3–A, and yielded 44¼ bushels per acre in 1895, showing effects of full supply of nitrogen, and also of phosphoric acid and potash, a complete manure giving in that year, with the exception of the plot continuously manured with farmyard manure, the maximum yield of the whole series.

The 'AA' series (1–AA, 2–AA, 3–AA and 4–AA) is identical with the A series, except that 275 lbs. of nitrate of soda has been every year since 1868 substituted for ammonia salts, that quantity of nitrate containing the same amount of nitrogen as 200 lbs. of ammonia salts. The results are similar to those of 'A' plots, except that no effect is shown of exhaustion of potash; the 2–AA plot without potash yielding even better than the 4–AA plot with full supply.

Plot 7–2 has been continuously manured with 14 tons of

[1] All the '3' and '4' plots have received soda and magnesia salts yearly, in addition to potash.

farmyard manure, and yielded in 1895 the maximum crop of 49½ bushels per acre, showing the effect of full or over supply of all necessary plant food. There are various other plots, but the above series will be sufficient to illustrate the points to which we desire to call attention.

Now, needless to say, the tabulated records of the Rothamsted experiments, in addition to the influence of exhaustion or full supply of nitrogen or minerals, or both, show also the varying effects of season, both on quantity and quality; and, summarizing the relative effects of manures and of seasons, it has been shown by Lawes and Gilbert very fully with regard to wheat, and similarly as to barley,[1] that: (1) exhaustion of nitrogen or minerals, or both, as distinct from full supply of either or both, has had definite effects on quality as well as quantity when the results of a series of years are taken for comparison; but (2) whilst definite general or average effects on quality are indicated, there is considerable variation from year to year, and the effects on quality due to manurial conditions are on the whole far less marked than those due to climatic conditions affecting growth and maturation. The differences in the quality of the grain grown on plots which have for many years received either (1) no manure, (2) different artificial mixtures, or (3) farmyard manure, are less, as a rule, in any one year than the differences in quality observable in grain grown on similarly treated plots in different seasons. Or, to put it briefly, quality of grain is affected less by manurial than by climatic conditions. Still, as before stated, the differences in quality with different manurial conditions when taken over a series of years are intrinsically considerable. And having now indicated the different manurial conditions, we have to consider what are the data available for assessing the relative quality for malting purposes of the produce of the various differently manured plots.

2. *Records relating to Quality of Produce*

There are published records of: 1. Weight per imperial bushel of the dressed grain of the various plots. 2. Weight

[1] *Journal of the Chemical Society*, 1884, p. 305: 'Agricultural Investigations at Rothamsted.' Lawes's *Agricultural Trust Lectures*, published by U.S. Department of Agriculture, 1895, p. 59.

of grain per 100 of straw, as calculated from the record of quantity of grain and straw respectively. 3. Analysis of the ash of the grain. In addition to these records we shall refer to the appearance of the samples of grain which for every plot in each year have been preserved at Rothamsted, and have been placed at our disposal by Sir John B. Lawes and Sir J. Henry Gilbert, and to the examination by physical and chemical methods of certain samples from the 1894 and 1895 crops.

We had first to consider how far it is possible to form a reliable opinion on malting quality as affected by manurial conditions when these data are considered separately or together.

1. Weight per imperial bushel alone is a very fair criterion of the quality of grain for milling purposes, but it is far from being a criterion of equal value for malting purposes. The difference between the market values of any two measures of wheat for milling of the same 'natural' weight will be very small, whilst barleys for malting purposes of equal 'natural' weight frequently vary in market value as much as 50 per cent., and occasionally more. The dry substance of grain having a specific gravity of about 1·5, it is obvious that weight per bushel is largely dependent on the moisture content of the grain at the time of weighing, and this is not available. The percentage of light grain removed in dressing is a valuable datum. A record of this has been preserved at Rothamsted, and with 'weight per bushel' affords good evidence of 'size of grain'.

Assuming, as we may, the conditions of grading to be equal for the various samples, 'weight per bushel' may still be high with very poor malting quality, and may be moderate with very good quality. Whilst the best samples of malting barley will almost always have a weight per bushel of at least 54 lbs. (with normal moisture content), yet samples of unripe, hard, steely grain will frequently give this weight and more. Anything under 52½ lbs., on the other hand, will almost always mean a high moisture content or small thin grain, which, though possibly of good quality in other respects, will yield a low extract to the brewer when malted.

2. Grain per 100 of straw is not a criterion so easy of application; but when it is remembered that (unlike wheat)

the paleae which form the husk of barley are adherent to the grain, and yet partake of the character and composition of the straw, it is most probable that a crop which has 'run to straw' will yield a more or less husky grain, and, other things being equal, a husky grain is an inferior grain for malting purposes.

If now we consider 'weight per bushel' and 'grain to 100 of straw' together, and take a long series of years, we may fairly go so far as to say that with low weight per bushel, say, under $52\frac{1}{2}$ lbs., and with also low weight of grain per 100 of straw, there is a strong presumption that the grain will be of comparatively low malting value.

As the weight per bushel, recorded for a long series of years, will be some indication of the size of the grain on the different plots, so, although not so definitely, the ratio of grain to straw will probably be found to have some relation to maturation. With overmuch straw, maturation of grain, both before and after cutting, is not likely to be so perfect as with a normal ratio. The grain is likely to come to maturity later, and there is more probability of uneven ripening, and probably also more difference in the ripeness of individual corns on the same spike, for it is an observed fact that the lower corns mature first and the upper ones later, and with straw heavy, and 'holding out' longer, this difference is likely to be more marked. After cutting, and before harvesting, overmuch straw in proportion to grain will not favour the mellowing of the grain, which is the second and by no means unimportant stage of that complete maturation which is associated with the best malting qualities.

On the other hand, with abnormally high ratio of grain (or very little straw) the straw may be weak in texture. If the crop is light, this will not be of much moment as affecting quality of grain, but with heavy crops there would be conditions favourable to 'lodging', and consequent loss of quality.

3. With regard to wheat, a very extended series of analyses of the Rothamsted produce shows a general connection between high nitrogen content and good quality, and the reverse. There are, however, many exceptions. With regard to barley, the most we can say is, that there is a probability

that high relative nitrogenous to carbohydrate content of grain is generally found in grain where the low quality is due both to thinness of grain and to imperfect ripening. Barleys of good quality, however, also not unfrequently yield a high percentage of total nitrogen. No determinations of nitrogen are available for the barley grown on the Rothamsted plots, but Sir Henry Gilbert, in the lecture before referred to, tells us that 'the percentage of nitrogen is almost invariably lower in seasons of high maturation'. We have estimated the total nitrogen in the samples of eight plots of the 1894 growth, and in those of eleven samples of 1895 growth; and the results are given in Table XVIII, p. 176. We may here say that we have found certain differences in the character of the nitrogenous as well as the carbohydrate matter of barley of different qualities and conditions of growth. All that can fairly be said with regard to total nitrogen content is, that where over a series of years with certain manurial treatment it is on the average high, and this characteristic is combined with low weight per bushel and low ratio of grain to straw, the presumption is strengthened that the particular treatment is not favourable to growth of grain of good malting quality.

A summary of many analyses of the ash of barley grown at Rothamsted under different conditions of manuring is given by Sir Henry Gilbert in his lecture, and, to use his own words, 'they forcibly illustrate the much greater influence of seasons than of manures on the composition of barley grain'. Whilst the composition of the straw ash varies much, that of the grain ash varies little, with different manurial conditions, and variations in the relative amounts of the mineral constituents of the grain are not consistently coincident with variations in quality.

Before proceeding to describe the appearance of the grain samples preserved at Rothamsted during the period we are dealing with, and the results we have obtained by a detailed examination of some of them, we may consider how far the data already mentioned afford evidence of the effect of manurial conditions on quality when they are tabulated for different manurial conditions and averaged over a long series of years, and especially how far a progressive tendency of such of these data as are on record to assert themselves in the

later years of such a long period renders this evidence stronger still.

Table XVI shows the weight per imperial bushel of dressed grain and the weight of grain to 100 of straw, averaged for twenty years, 1852–71, for twenty years, 1872–91, and for four years, 1892–95, for each of the thirteen plots which we have already referred to. The table also gives the increase or decrease in average 'weight per bushel' and 'grain to 100 straw' in the later as compared with the earlier periods. The plots are arranged in the order of the average weights per bushel for the forty-year period, 1852–91.

The average 'weights per bushel' on the respective plots do not vary materially as between the two twenty-year periods, but they are higher for the average of the four years 1892–95 in every case than for the average of the second twenty years, 1872–91. This is due to the fact that three out of the four years, viz., 1892, 1893, 1895, were years of considerably over-average 'weight per bushel'.

The average ratio of grain to straw was considerably higher for the second than for the first twenty years over the plots generally, but the average increase in ratio was much greater on some plots than on others. On the other hand, for the four years 1892–95 the average ratio was lower than in the immediately preceding twenty years (1872–91), but on some plots lower and on some higher than in the first twenty years (1852–71).

The columns 4, 5, 6, and 10, 11, 12, therefore, apparently indicate the general relative tendency of weight per bushel and ratio of grain to straw to increase or decrease under the respective manurial treatments. But it must be remembered that only the four more recent seasons are compared with the earlier period, and it is possible that the special characteristics of these particular seasons may have favoured some plots more than others. The different periods were not, of course, alike in atmospheric conditions, but the differences due to these conditions are probably indicated in the averages given in the last line of the table, and, comparing the increases and decreases on the different plots with these averages, there are marked variations, pointing to the effects of prolonged supplies of the different manures.

TABLE XVI.—Weight per Imperial Bushel of Dressed Grain, and Grain to 100 Straw, for average of 20 years 1852–71, average of 20 years 1872–91, and average of 4 years 1892–95, with increases and decreases of averages during the respective periods. In order of Weight per Bushel for average of 40 years 1852–91.

Plots		Manures	1852–71	1872–91	1892–5	1872–91 + or − 1852–71	1892–5 + or − 1852–71	1892–5 + or − 1872–91	1852–71	1872–91	1892–5	1872–91 + or − 1852–71	1892–5 + or − 1852–71	1892–5 + or − 1872–91	Plots
			Weight per bushel	Weight per bushel	Weight per bushel	Weight per bushel	Weight per bushel	Weight per bushel	Grain to 100 straw	Grain to 100 straw	Grain to 100 straw	Grain to 100 straw	Grain to 100 straw	Grain to 100 straw	
			lbs.	lbs.	lbs.	lbs.	lbs.	lbs.							
1	7–2	Farmyard manure	$54\frac{3}{8}$	$54\frac{1}{4}$	$55\frac{1}{4}$	$-\frac{1}{8}$	$+\frac{7}{8}$	+1	87·4	83·1	77·9	−4·3	− 9·5	− 5·2	7–2
2	4–A	Ammonia salts, superphosphate, and alkaline salts	54	$54\frac{1}{8}$	$54\frac{3}{4}$	$+\frac{1}{8}$	$+\frac{3}{4}$	$+\frac{5}{8}$	82·6	87·4	92·1	+4·8	+ 9·5	+ 4·7	4–A
3	4–AA	Nitrate of soda,[1] superphosphate and alkaline salts	$53\frac{3}{8}$	54	$54\frac{7}{8}$	$+\frac{5}{8}$	$+1\frac{1}{2}$	$+\frac{7}{8}$	77·5	85·3	81·7	+7·8	+ 4·2	− 3·6	4–AA
4	2–AA	Nitrate of soda[1] and superphosphate	$53\frac{3}{8}$	$53\frac{1}{4}$	$54\frac{3}{4}$	$-\frac{1}{8}$	$+1\frac{3}{8}$	$+1\frac{1}{2}$	81·7	90·4	89·2	+8·7	+ 7·5	− 1·2	2–AA
5	2–0	Superphosphate only	$53\frac{1}{4}$	53	$54\frac{1}{2}$	$-\frac{1}{4}$	$+1\frac{1}{4}$	$+1\frac{1}{2}$	96·5	106·1	96·2	+9·6	− 0·3	− 9·9	2–0
6	4–0	Alkalies and superphosphate	$53\frac{3}{8}$	$52\frac{5}{8}$	$54\frac{5}{8}$	$-\frac{3}{4}$	$+1\frac{1}{4}$	+2	96·1	100·8	85·6	+4·7	−10·5	−15·2	4–0
7	2–A	Ammonia salts and superphosphate	$53\frac{3}{8}$	$52\frac{1}{4}$	$53\frac{1}{8}$	$-1\frac{1}{8}$	$-\frac{1}{4}$	$+\frac{7}{8}$	86·0	95·5	93·9	+9·5	+ 7·9	− 1·6	2–A

Plots		Manures	1852–71	1872–91	1892–5	1872–91 + or – 1852–71	1892–5 + or – 1852–71	1892–5 + or – 1872–91	1852–71	1872–91	1892–5	1872–91 + or – 1852–71	1892–5 + or – 1852–71	1892–5 + or – 1872–91	Plots
			Weight per bushel	Weight per bushel	Weight per bushel	Weight per bushel	Weight per bushel	Weight per bushel	Grain to 100 straw	Grain to 100 straw	Grain to 100 straw	Grain to 100 straw	Grain to 100 straw	Grain to 100 straw	
			lbs.	lbs.	lbs.	lbs.	lbs.	lbs.							
8	3–A	Ammonia salts and alkaline salts	52¾	52½	54	– ¼	+1¼	+1½	85·7	90·3	83·6	+4·6	– 2·1	– 6·7	3–A
9	3–AA	Nitrate of soda[1] and alkaline salts	52¼	52¾	54⅜	+ ½	+2⅛	+1⅝	79·4	83·7	83·2	+4·3	+ 3·8	– 0·5	3–AA
10	3–O	Alkaline salts only . .	53	51⅞	53¾	–1⅛	+ ¾	+1⅞	92·3	94·9	78·8	+2·6	–13·5	–16·1	3–O
11	1–AA	Nitrate of soda[1] only .	52	52⅛	53⅜	+ ⅝	+1⅜	+1¼	84·7	88·7	88·1	+4·0	+ 3·4	– 0·6	1–AA
12	1–A	Ammonia salts only .	52⅛	52	53¼	– ⅛	+1⅛	+1¼	88·5	93·9	84·5	+5·4	– 4·0	– 9·4	1–A
13	1–O	Unmanured . . .	52⅜	51¾	53⅝	– ⅝	+1¼	+1⅞	85·8	95·4	81·4	+9·6	– 4·4	–14·0	1–O
		Average .	53	52¾	54¼	– ¼	+1¼	+1½	85·1	89·8	85·6	+4·7	+ 0·5	– 4·2	

[1] Nitrate of soda, 1868 and since. First six years, 1852–57, 400 lbs. ammonia salts per acre per annum; next ten years, 1858–67, 200 lbs. ammonia salts per acre per annum.

ROTHAMSTED PLOTS

TABLE XVII.—Averages for 40 years, 1852–91, of (1) Imperial Bushels per Acre of Dressed Grain; (2) Weight per Imperial Bushel of Dressed Grain in pounds; and (3) Offal Grain per 100 total Grain; also (4) Weight per 1,000 Corns of average samples, representing 24 years (1872–95), in grammes. In order of Weight per Bushel of Dressed Grain

Relative quality	Plots	Manures	1 Bushels per acre	2 Weight per bushel	3 Offal grain per 100 total grain	4 Weight per 1,000 corns 1872–95,	Plots
				lbs.		grammes	
1	7–2	Farmyard manure	$48\frac{5}{8}$	$54\frac{1}{4}$	4·4	44·7	7–2
2	4–A	Ammonia salts, superphosphate and alkaline salts	$43\frac{1}{2}$	54	3·9	42·1	4–A
3	4–AA	Nitrate of soda,[1] superphosphate and alkaline salts	$45\frac{1}{2}$	$53\frac{5}{8}$	4·9 3·9 to 5·3%	41·0	4–AA
4	2–AA	Nitrate of soda [1] and superphosphate	$45\frac{3}{4}$	$53\frac{1}{4}$	5·0	40·4	2–AA
5	2–O	Superphosphate only	$21\frac{3}{4}$	$53\frac{1}{8}$	4·7	39·3	2–O
6	4–O	Superphosphate and alkaline salts	$22\frac{3}{8}$	53	4·6	39·1	4–O
7	2–A	Ammonia salts and superphosphate	$42\frac{3}{4}$	$52\frac{7}{8}$	5·3	38·6	2–A
8	3–A	Ammonia salts and alkaline salts	$31\frac{3}{8}$	$52\frac{5}{8}$	5·7 5·5	41·4	3–A
9	3–AA	Nitrate of soda [1] and alkaline salts	$33\frac{1}{2}$	$52\frac{1}{2}$	6·5 to	41·2	3–AA
10	3–O	Alkaline salts only	18	$52\frac{1}{2}$	5·5 6·5%	39·1	3–O
11 •	1–AA	Nitrate of soda [1] only	$32\frac{3}{4}$	52	7·0 over	40·5	1–AA
12	1–A	Ammonia salts only	29	52	6·6 6·6%	40·3	1–A
13	1–O	Unmanured	$16\frac{1}{2}$	52	6·9	36·7	1–O
		Average	..	53	5·3	40·3	

[1] Nitrate of soda, 1868 and since. First six years, 1852–57, 400 lbs. ammonia salts; next ten years, 1858–67, 200 lbs. ammonia salts per acre per annum.

Table XVII gives the average produce of dressed grain in imperial bushels, and the average weight per bushel of dressed grain for the forty years, 1852–91. It also gives the percentage of light grain and other 'tailings' removed by dressing. A high proportion of light grain almost certainly corresponds with small size in the grain from which it is taken. The figures, accordingly, follow pretty closely in order those of weight per bushel.

As regards size of grain, the tables give conclusive evidence of the relative effects of the different manures, and the plots fall into the three classes indicated. First, and best, manures supplying phosphates; secondly, manures supplying alkaline salts without phosphates; and thirdly, manures supplying neither.

3. *Samples from selected Plots,* 1894 *and* 1895

Table XVIII, on the next page, gives all the available data (including the results of our analyses of the samples) of eight plots in 1894 and eleven plots in 1895. The order in which the plots are enumerated is that of their general malting quality as assessed by inspection of the samples prior to any other tests.

The quality of grain which is called 'kindliness' is a combination of mellowness or mealiness, good shape of grain, and thinness of husk, all of which qualities are closely connected with, and dependent on, good conditions of maturation. We believe the appearance of the cut grain as shown by the 'Korn Prüfer' to be a good indication of maturation, and, in fact, generally speaking, to correspond with 'kindliness'. An experienced judge of malting barley will not need the aid of this instrument in assessing malting quality, but in comparing a series of samples its use enables us to represent by the proportion of 'mellow' to 'steely' fractures what could not easily be otherwise expressed, however apparent such qualities might be to the eye and hand.

It should be stated that when a grain shows a semi-white fracture, as will be the case with many grains in all samples, and with most grains in some samples, such grains are counted at one-half the value of the fully white grains; thus a sample showing 40 white, 40 semi-white, and 20 steely grains would be considered to have 60 mealy grains per 100.

ROTHAMSTED PLOTS

TABLE XVIII.—Samples from Eight Plots in 1894, and from Eleven Plots in 1895. In order of Relative General Malting Quality in each year

Relative Quality	Plots	Manures	Bushels per acre dressed grain	Weight per bushel	Total grain to 100 total straw	Weight of 1,000 corns in grms.	Mealy corns per 100	Total nitrogen: % of dry grain	Fibre: % of dry grain	Fat: % of dry grain	Ash: % of dry grain	Plots
		1894										
1	4–A	Ammonia salts, superphosphate and alkaline salts	41⅜	54⅛	77·7	40·6	61	1·33	4·95	1·84	2·42	4–A
2	2–AA	Nitrate of soda and superphosphate	41	53⅛	74·1	38·1	68	1·33	4·58	2·14	2·42	2–AA
3	4–AA	Nitrate of soda, superphosphate and alkaline salts	45	54¼	69·2	40·3	53	1·49	4·90	1·72	2·41	4–AA
4	2–O	Superphosphate only	16¾	52⅛	85·6	38·4	70	1·25	5·10	1·78	2·42	2–O
5	4–O	Superphosphate and alkaline salts	13⅛	52⅛	79·2	40·0	56	1·29	5·13	1·95	3·10	4–O
6	2–A	Ammonia salts and superphosphate	34⅞	51⅞	77·0	35·7	45	1·53	5·08	1·44	2·31	2–A
7	7–2	Farmyard manure	44⅝	52⅜	57·7	39·0	22	1·45	4·69	1·50	2·88	7–2
8	1–O	Unmanured	10	51⅛	70·3	38·1	66	1·29	5·09	1·67	2·42	1–O
		1895										
1	2–O	Superphosphate only	16⅞	54⅝	102·5	43·2	51	1·54	4·92	1·78	2·26	2–O
2	4–A	Ammonia salts, superphosphate and alkaline salts	44¼	53⅜	110·3	43·7	48	1·63	5·68	1·85	2·03	4–A
3	4–AA	Nitrate of soda, superphosphate and alkaline salts	37⅝	54⅜	94·8	45·0	43	1·71	5·35	1·55	2·26	4–AA
4	4–O	Superphosphate and alkaline salts	16¼	55⅜	86·6	45·9	36	1·67	5·37	1·55	2·27	4–O
5	7–2	Farmyard manure	49½	56⅛	92·8	48·1	33	1·76	5·30	2·33	2·27	7–2
6	2–AA	Nitrate of soda and superphosphate	39¾	53⅞	100·4	42·0	49	1·71	5·56	1·61	1·67	2–AA
7	3–O	Alkaline salts only	13¼	54⅛	89·8	43·7	39	1·67	5·53	1·97	2·39	3–O
8	2–A	Ammonia salts and superphosphate	29⅝	52⅝	111·1	38·9	47	1·70	5·54	2·34	1·90	2–A
9	1–O	Unmanured	13⅜	54⅛	87·7	42·2	50	1·54	5·54	1·60	2·14	1–O
10	3–A	Ammonia salts and alkaline salts	28	54¼	94·0	44·7	32	1·71	5·11	2·10	1·78	3–A
11	3–AA	Nitrate of soda and alkaline salts	28¾	54¼	94·9	44·5	32	1·92	5·56	2·26	1·67	3–AA

Maturation, as indicated by the mealiness of the grain, follows general quality closely in both years. The most prominent exceptions are the barleys of Plots 2–O and 1–O, which, though better matured than any other, are rather small. Weight per bushel also in 1894 generally follows quality. It might at first sight be supposed that 'weight of 1,000 corns' would be the best accurate test of size of grain, but we have found that the specific gravity of unripe, and generally badly matured grain is higher than that of 'kindly' grain. Contrary to what might be expected, the specific gravity of the husk is greater than that of the flour of the barley, and the hardier, huskier and steelier the barley the greater is the weight per 1,000 corns in samples which appear to the eye about equal in size. For instance, the barley of Plot 2–O in 1895 appears to the eye much stouter (as well as better shape) than that of 3–A and 3–AA, and notwithstanding this 1,000 corns of each of the two latter plots are heavier.

The nitrogen content of the grain does not follow general quality closely in either year, but the most mealy sample has, as is to be expected, the least nitrogen in both years.

Fibre is a measure of the huskiness of the grain, and generally is in inverse ratio to 'kindliness'. Ash does not always vary in total amount with quality, and the conditions affecting its amount are too complex for full discussion here.

For comparison we append two analyses: (1) of a kindly well-matured barley (grown near Downton, Wilts, after wheat); and (2) of an imperfectly matured sample (grown in Dorestshire—previous cultivation not known). The results are calculated on the dry matter of the grain.

	(1) Per cwt.	(2) Per cwt.
Starch	50·50	48·40
Sugars	2·54	2·73
Gums (amylans, etc.)	2·55	3·08
Nitrogen	(1·42)	(2·01)
N. × 6·25 = albuminoids, so called	8·88	12·58
Fat, etc. (petroleum extract)	2·02	2·09
Ash	2·67	1·67
Crude fibre	4·68	4·75
Undetermined substances by difference	26·16	24·70
including 'Furfuroids' (= Furfural × 2)	(10·86)	(11·39)
	100·00	100·00

4. *The Rothamsted Collection of Samples*

We were given an opportunity of examining the collection of samples preserved at Rothamsted, representing the produce of every plot for every one of the forty-four years. It is needless to say that a complete examination (to say nothing of a complete assessment of relative values) of this remarkable and truly unique collection would be an enormous task. The fact that they have necessarily been artificially dried to some extent, for the purpose of preservation, has changed the original colour of the grain. This altered appearance is much the same as that produced by the familiar process of 'sweating' barley on kilns before steeping, and can be partly allowed for. But there is no doubt that, in addition to this, there has been a change from lapse of time alone, and this may or may not be considerable. All that we felt justified in attempting was to sort the samples representing the growth of thirteen plots for the last twenty-four years (1872–95) into four qualities: (1) Samples of over-average size of grain, combined with good general quality (or, what is practically the same thing, good maturation). (2) Samples of small-sized grain, but of otherwise good maturation. (3) Large-sized samples with low general quality. (4) Small-sized samples with low general quality. As nearly as could be judged by eye inspection, and comparison with a tested sample, the samples were put into classes 1 and 2 and classes 3 and 4 respectively accordingly as they appeared to be over or under 40 grammes per 1,000 corns.

Colour of the samples (apart from changes in drying and from lapse of time) is obviously mainly a fortuitous quality, and was taken no account of in making the above classification.

The number of samples from each plot which fell into each of the four classes is given in Table XIX, opposite.

A weighed quantity of grain was taken from each sample, and the samples so taken mixed to give an average sample for each plot for the twenty-four years.

The weight per 1,000 corns and number of mealy corns per 100 were determined in each of these average samples and the results are given in the table. The relative weight per 1,000 corns, combined with 'weight per bushel', gives an indication of size of grain; but whether value attaches to the

TABLE XIX.—Classification of the Samples preserved at Rothamsted of Thirteen Barley Plots of the Twenty-four Years 1872–95. Number of samples in each class. Class 1. Barley of better than average maturation and over-average size. Class 2. Barley of better than average maturation and under-average size. Class 3. Barley of under-average maturation and over-average size. Class 4. Barley of under-average maturation and under-average size. Also average weight per bushel, weight of 1,000 corns, and mealy corns per 100 in average sample for each plot. In order of Relative General Malting Quality.

Relative quality	Plots	Manures	Number of samples in each class: 1	2	3	4	Avg. weight per bushel	Weights of 1,000 corns in grammes	Mealy corns per 100	Plots
1	4–A	Ammonia salts, superphosphate and alkaline salts	18	2	4	0	54¼	42·1	67	4–A
2	2–O	Superphosphate only	15	5	3	1	53¼	39·3	71	2–O
3	4–AA	Nitrate of soda, superphosphate and alkaline salts	13	6	5	0	54⅛	41·0	59	4–AA
4	2–AA	Nitrate of soda and superphosphate	9	10	2	3	53½	40·4	61	2–AA
5	4–O	Superphosphate and alkaline salts	10	3	8	3	53	39·1	69	4–O
6	2–A	Ammonia salts and superphosphate	6	9	3	6	52½	38·6	55	2–A
		Average of six plots *with* phosphate	12	6	4	2	53½	40·1	64	
	7–2	Farmyard manure	8	3	9	4	54⅜	44·7	48	7–2
8	1–O	Unmanured	6	6	9	3	52⅛	36·7	62	1–O
9	3–O	Alkaline salts only	5	1	11	7	52¼	39·1	62	3–O
10	3–A	Ammonia salts and alkaline salts	3	2	10	9	52¾	41·4	53	3–A
11	1–A	Ammonia salts only	2	4	8	10	52¼	40·3	54	1–A
12	1–AA	Nitrate of soda only	2	4	5	13	52⅜	40·5	51	1–AA
13	3–AA	Nitrate of soda and alkaline salts	1	2	8	13	53	41·2	52	3–AA
		Average of six plots *without* phosphate	3	3	9	9	52½	39·9	56	

percentage of mealy corns depends on the nature of the changes which the grain has undergone. On this point all we can say is that the drying of the samples and their long storage have increased rather than diminished the evidence of maturation.

Maturation, or what is nearly the same thing, 'kindliness', as judged by eye inspection is confirmed as closely as perhaps can be expected by the 'Korn Prüfer' test in the average samples representing twenty-four seasons. The only noticeable exceptions are: (1) 4–O, which cut more mealy than 4–A (although the sample did not look so kindly), and much more so than 4–AA, both of which plots are placed higher in respect of number of years falling into the first two classes; (2) the produce of the farmyard manure plot, on the other hand, was very steely—more so than would be expected from external appearance.

Weight per 1,000 corns (as before stated) has to be qualified by considering the specific gravity of the grain before it becomes a measure of size. Table XVII (in which the figures of this column also appear) shows that weight per 1,000 corns follows weight per bushel in the respective classes, but that it is out of proportion high with nitrogenous manures without phosphates.

These are just the conditions which give (generally) steely and husky grain, and therefore grain of high specific gravity. The close adherence of the husk to the endosperm in this class of barley implies greater weight for individual grains than with the more 'wrinkled' husk of the kindlier barleys, which appear to the eye of about the same size.

The plots have been arranged in this table (XIX) in order of general quality, except that perhaps plot 2–A (ammonia salts and superphosphate) should have been put below the unmanured plot, 1–O; and 7–2 (farmyard manure), on account of its size of grain, would, perhaps, generally be valued higher than it is placed. The first six plots, however, are brought together, to show the contrast between phosphate and no phosphate, which the averages do in a striking manner.

The farmyard manure plot is placed alone. This plot gives the maximum yield of the whole series (48⅝ bushels for the average of forty years). The grain is stout and heavy, but somewhat coarse.

The position of plot 1–O (no manure for forty-four years) in respect of quality is interesting. With the lowest quantity it has yielded distinctly better-quality grain for the last twenty-four years than any other plot not receiving phosphates, even where they have, and perhaps to some extent in consequence of their having, had abundant supplies of nitrogenous manures, or alkaline salts, or both together. The worst plots of the whole series are the two nitrate plots, 1–AA and 3–AA, without phosphates. The yield on these two worst (as to quality) plots is more than 25 per cent. less than on the otherwise similar plots, 2–AA and 4–AA, with phosphate added, and the difference in value per quarter is probably quite as high a percentage.

The Rothamsted Plots considered seriatim

The facts relating to each of the thirteen plots tabulated in Tables XVI to XIX may now be presented separately for each plot, with a view to drawing such general deductions as they seem to warrant. Remembering that size of grain and maturation are the important factors affected by manurial conditions, and that the available data are valuable in proportion as they are evidence on these points, the notes on each plot will be arranged to bring together the various data respecting (1) yield per acre, (2) size, (3) maturation, and (4) general quality, which may be regarded as a combination of the other factors, with something added for a symmetrical balance of good points which is revealed by their general appearance. The plots are described in the order of general malting quality, as arranged in Table XIX.

(a) *Plots with Phosphate*

4–A. Ammonia salts and full minerals as 4–O

1. Yield, 43½ bushels per acre for average of 40 years, only exceeded by nitrate and mineral plots 4–AA and 2–AA and farmyard manure plot 7–2.
2. Weight per bushel for average of 40 years, 1852–91, 54 lbs., only exceeded by farmyard manure plot (54¼). Proportion of tailing corn lowest of 13 plots. Size of dressed grain best of 8 samples in 1894, not so good in 1895.
3. Grain to straw below several incompletely manured plots, and about the same as farmyard manure plot for 40 years, 1852–91,

but with decided tendency to increase in recent years. Maturation second-best of 8 plot samples in 1894, considerably above average in 1895.

4. General quality, best of 8 plot samples in 1894, only exceeded by 2–O in 1895. Plot 4–A yields very much better quality than 2–A, indicating that a full supply of potash, soda, and magnesia, or some of them, is helpful to malting quality where, with ammonia and phosphates constantly applied, heavy crops are taken year after year. This plot gives the best average malting quality of the whole series. Many of the samples, especially in the early eighties, are very fine, and over the average of 24 years the grain is much better than the generality of malting barley grown in ordinary practice.

2–O. $3\frac{1}{2}$ cwts. superphosphate every year for 44 years

1. The average yield for 40 years, 1852–91, is $21\frac{3}{4}$ bushels, or 30 per cent. above the unmanured plot, but less than half that of several fully manured plots.

2. The weight per bushel is fairly good, $1\frac{1}{8}$ lbs. above that of the unmanured plot for 40 years, 1852–91, and about the average of all the plots. It appears to show no tendency in recent years to decline. The proportion of tailing corn is very low, being lower on only 3 out of 13 plots. The grain was small in 1894, of fair size in 1895, and for the last 24 years has been generally much above average; although, owing to low specific gravity, 1,000 corns weigh less than those of many plots which are much inferior in quality.

3. Grain to 100 of straw is higher than on any other plot, both over the 40 years, 1852–91, and also during recent years, showing a tendency as compared with the other plots to improve. In both 1894 and 1895 it was better matured, as judged by the mealiness, than that of any other of the 8 and 11 plots respectively. The average sample representing growth of 24 years also shows very high maturation.

4. General quality was rather low in 1894 owing to smallness of grain, but highest of 11 samples in 1895. For the years 1872–95 general quality only very little inferior to the best plot, 4–A.

4–AA. Nitrate of soda and full minerals as 4–O

1. Yield, $45\frac{1}{2}$ bushels per acre for 40 years, 1852–91, $2\frac{1}{4}$ bushels per acre more than 4–A (ammonia salts and full minerals).

2. Weight per bushel high. Slightly lower than 4–A for average of 40 years, but higher in recent years. Proportion of tailing low. Size of dressed grain, 1894 and 1895, over average; considerably higher than 2–AA in both years.

3. Grain to 100 of straw low. Maturation lower than 2–AA (without potash, soda and magnesia) in 1894 and 1895.

4. General quality slightly above 2–AA both in 1894 and 1895.

2–AA. Nitrate of soda and superphosphate

1. Maximum yield of 12 plots with artificial manure ($45\frac{3}{4}$ bushels per acre average of 40 years, 1852–91) only exceeded by farmyard manure plot (48 bushels).

2. Weight per bushel above average of 13 plots, but less than with the same manure plus alkaline salts. Proportion of tailing low. Size of dressed grain small in 1894. Only one of 8 samples was smaller, viz. 2–A. In 1895 only two were smaller, viz., 2–A again and 1–O (unmanured).

3. Grain to 100 of straw low, but relatively higher in recent years. Maturation high. Second-best of 8 samples in 1894, and third of 11 in 1895.

4. General quality differs little from 4–AA for average of last 24 years. Rather smaller grain, but quite as kindly.

4–O. Superphosphate and alkaline salts

1. Yield very slightly above 2–O (superphosphate only); about one-half that of fully manured plots.

2. Weight per bushel equal to average of all plots, but slightly less than 2–O. Well maintained relatively to other plots in recent years. Proportion of tailing low, but slightly higher than 2–O. Size of dressed grain, medium in 1894, good in 1895, and for last 24 years above average.

3. Grain to 100 of straw very low, and falling considerably in recent years. Maturation under average in 1894 and 1895, and distinctly inferior to 2–O. Average sample for 24 years second-best, and nearly equal to 2–O.

4. Market value both in 1894 and 1895 less than 2–O; average sample for 24 years is inferior in appearance to 2–O, but the 'Korn Prüfer' and weight tests come out better than would be expected.

2–A. Ammonia salts and superphosphate

1. Yield, 42 bushels per acre for average of 40 years, but some falling-off in last four years relative to other plots.

2. Weight per bushel very slightly under average, and apparently falling as compared with other plots in last four years. Proportion of 'tailing' about average. Size of dressed grain smallest of 8 samples in 1894, and of 11 samples in 1895; also generally under any foregoing plots for the last 24 years.

3. Grain to 100 of straw slightly over average, and apparently with a tendency to increase. Maturation low in 1894, fairly good in 1895. In sample representing 24 years generally low.

4. Market value, only one of 8 samples lower in 1894, and only one of 11 lower in 1895. General quality of average sample for 24 years distinctly inferior to 2–AA.

(b) *Farmyard Manure*

7–2. Farmyard manure, 14 tons every year for 44 years

1. Yield, maximum of all plots for average of 40 years, viz., $48\frac{5}{8}$ bushels per acre.

2. Weight per bushel, maximum of all plots for average of 40 years, viz., $54\frac{1}{4}$ lbs. per bushel. Proportion of tailing, second lowest to 4–A of 13 plots.

3. Grain to 100 of straw low for 40 years and nearly lowest of any plot for 4 years, 1892–95, and evidently declining. This is the only one of the 13 plots which shows an absolute decline in each successive period. Maturation much lower than any of 8 plots in 1894, and with 3–A and 3–AA lowest of 11 in 1895. Grain in both years is coarse in quality and thick-skinned. Table XIX shows that this has been the general character of the grain for many years.

4. General quality nearly minimum both in 1894 and 1895, only very slightly better than unmanured plot in either year. Average general quality for last 24 years lower than any of the '4' and '2' plots (those receiving artificial minerals, including phosphates). There is evidence of more accumulation of plant food in the soil of this plot than is conducive to malting quality.

(c) *Plots without Phosphate*

1–O. No manure for 44 years

1. Minimum yield of $16\frac{1}{2}$ bushels per acre over the 40 years 1852–91.

2. Very low weight per bushel over the same period, with 1–A and 1–AA the lowest of the 13 plots, but not quite the lowest for the last four years, 1892–95. As compared with the other plots, weight per bushel is well maintained in recent years. The proportion of tailing corn is higher than on any other plot for the 40 years, except on 1–AA (nitrate of soda only), and the 'size' very small in 1894 and 1895, and also in average sample of last 24 years.

3. Grain to 100 of straw is rather below the average of all the plots for the 40 years 1852–91, and tends in recent years to decline more than most other plots. The grain of both 1894 and 1895 was considerably above average mealiness (i.e. well matured), being third of 8 plot samples examined in 1894, and second of 11 in 1895. That of an average sample representing growth of 24 years is also above the average.

4. The market value was lowest of 8 samples in 1894 (none of '3' series being then included), and lowest except those of the '3' series in 1895. The samples of the last 24 years have been small, but much better in general quality than from the great exhaustion of the soil would have seemed probable.

3–O. Potash, soda and magnesia salts only

1. Only slightly higher average yield than unmanured plot.

2. Weight per bushel very low, and falling. High proportion of tailing corn. Size of grain for past 24 years about equal to unmanured plot.

3. Grain to 100 of straw high for the 40 years 1852–91, but apparently now falling relatively to other plots. Lowest of any of 13 plots for four years 1892–95 (except farmyard manure plot, 7–2). Maturation as indicated by mealiness low in 1895, in average sample representing 24 years equal to unmanured plot, and better than the plots following.

4. Market value, of 11 samples only 3–AA lower in 1895.

3–A. Ammonia salts and alkaline salts

1. Yield, 31⅝ bushels, slightly above 1–A (ammonia salts only), but much lower than with superphosphate added.

2. Weight per bushel low. Proportion of 'tailing' over average.

3. Grain to 100 of straw rather under average. Maturation in 1895 lowest of 11 plot samples.

4. Market value, only one of 11 plot samples lower in 1895. General quality for past 24 years distinctly lower than unmanured plot, 1–O.

1–A. Ammonia salts only

1. Somewhat higher yield than with minerals only, but about 30 per cent. lower than with ammonia and minerals.

2. Weight per bushel very low, same as unmanured plot. Proportion of 'tailing' very high, only exceeded by unmanured plot, 1–AA (nitrate of soda only).

3. Grain to 100 of straw slightly above average of all plots for 40 years, 1852–91, but very low in recent years. Maturation of average sample representing 24 years very low.

4. General quality as judged by average sample very low. There is little to choose between this and the two following plots.

1–AA. Nitrate of soda only

1. Yield, 13 per cent. better than with ammonia salts only, but nearly 30 per cent. less than with superphosphate added.

2. Weight per bushel below average for 40 years. Proportion of tailing high.

3 and 4. Grain to 100 of straw, maturation, and general quality of last 24 years all very low.

3–AA. Nitrate of soda and alkaline salts

1. Yield, slightly above 1–AA (nitrate of soda only), but much below 2–AA and 4–AA (with superphosphate).

2. Weight per bushel below average of 13 plots for 40 years,

but with apparent relative tendency to rise. Proportion of tailing high. Size of grain very small for past 24 years.

3. Grain to straw lowest of 13 plots for 40 years, but with some tendency to relative increase in recent years. Maturation in 1895 very low, also for the past 24 years.

4. Market value 1895 lowest of 11 samples, and general quality for past 24 years lowest of all the plots.

5. General Conclusions

Taking now a general survey of the effects as illustrated at Rothamsted of applications of potash and other alkaline salts, phosphoric acid, and nitrogen in different combinations, and dealing with these three ingredients of manures in the order specified, there appears to be some evidence, not perhaps conclusive, but at any rate suggesting that the long-continued dressings of the alkaline salts have injuriously affected in the later years both quality and quantity on all the '3' plots.

In combination with ammonia salts and superphosphate, however, on plot 4–A, they have evidently done the reverse, for in the later years both quality and quantity have been better on this plot than on 2–A. That the results on the first-named plots are due to over-accumulation of alkaline salts in the soil is made probable by the fact that for the first twenty years there was an improvement, at any rate in quantity, due to their application, whilst for the second twenty years both quality and quantity have deteriorated.

Considerable effect seems to be produced on the straw by these salts. With exhaustion, or insufficient supply of potash, there is weak straw, and probably a tendency to 'lodging' where, with full supply of nitrogen, the crop is heavy. In a series of experiments on chalk soils in Norfolk, in 1886, applications of potash salts very considerably improved the barley crop, and some improvement in quantity, though not enough to be remunerative, and not apparent in the quality of the samples, was also shown in a very large series of trials carried out, on many different kinds of soil, in different parts of the south of England, by the Bath and West of England Society in 1887. It was shown, however, by Dr. J. A. Voelcker[1] that the Norfolk soil was exceptionally deficient

[1] Consulting chemist to the Royal Agricultural Society for over fifty years.

in potash, much more so than the Chalk soils in the south of England, which showed in the following year some, but much less, benefit from applications of potash salts. In 1889 another extensive series of trials in many localities under the auspices of the same Society showed a material gain in quantity in almost every case from the addition of chloride of sodium (common salt) to nitrate of soda and superphosphate, the increase in most cases being considerably greater than with potash. The reports of the trials in detail seem to indicate that the effect of the salt was to improve the character of the straw, but the recorded data were not sufficient to judge of its effect on the quality of the grain.

At Rothamsted apparently the 2–A plot, which (like 2–O and 2–AA) has received no potash, soda, or magnesia for forty-four years, is the only one of the series which has suffered materially, either in quantity or quality, from exhaustion of these minerals, and this has been pronounced only in the recent years. The crops yielded by this plot (with full nitrogen and phosphoric-acid supply) have been very heavy, and it would have been surprising if the very exceptional fact of no potash supply for so long a period had not produced by this time some effect. Why similar non-supply of potash has produced comparatively little effect on plot 2–AA, which has given larger crops than 2–A, is not so easy to explain, unless we could admit that soda (from the nitrate) has been able to partially replace potash, and this is not probable.

To sum up the evidence with regard to the influence of applications of potash salts on the quality of grain, they are only likely to be effective (as to quality) in cases of exceptional previous exhaustion or deficiency of potash in the soil, but probably quantity and quality of straw will show effects of such exhaustion earlier than the grain. It is doubtless for this reason that artificial mixtures, sold by the leading firms as grain manures, invariably and rightly contain a small percentage of potash in addition to a large percentage of the more needed (especially for the grain) phosphoric acid.

We are on surer ground when the influence of phosphoric acid on quality is considered. Sir Henry Gilbert tells us that 'in the case of our [Rothamsted] soil, at any rate, phosphatic manures have almost invariably a favourable

influence on the malting quality of the grain'; and as bearing on the relative effects of alkalies and phosphates 'the valuations almost invariably are lower for the "3" than for the "2" and "4" samples'.

It would appear from the particulars already given that no plot at Rothamsted from which phosphates have been omitted continues to give barley of good malting quality, whilst the plot 2–O, which has had no other dressing than 3½ cwts. per annum of superphosphate, generally yields a kindly, well-matured grain of very fair weight per bushel, though often small in body, as might be expected from the great nitrogen exhaustion. All the '2' plots (without potash, etc.), in fact, yield grain of better quality than the '3' plots (without phosphate), the difference being in general that the '2' samples are more kindly and less husky. Where nitrogenous manure is applied in the shape of ammonia salts, addition of potash, soda and magnesia to superphosphate has improved the quality (on plot 4–A), but where the nitrogen is given in the form of nitrate of soda the capacity of the soil at Rothamsted to grow barley has not apparently deteriorated much either in respect of quantity or quality from non-supply of alkaline salts; plot 2–AA (nitrate of soda and superphosphate) has in fact given very high crops, far above the average of the whole country, for forty-four years in succession, with entire absence of potash supply. Indeed, for the forty years, 1852–91, the average with nitrate and superphosphate was actually higher (on plot 2–AA) than with potash added (on plot 4–AA), and higher than was given by any other combination of artificials, whilst in respect of quality there has been little to choose between the two plots.

With regard to the influence of nitrogenous manuring on quality, the fact of cardinal importance is that assimilation of carbon by the plant and consequent building up of carbohydrate matter goes on only in proportion as there is nitrogen supply. That the Rothamsted plots, which have received no nitrogenous manures for so long a period as forty-four years, continue to give crops of corn equal to the average of the crops of many foreign countries, shows either how slowly nitrogen is completely eliminated from such a soil, or that there is some, at present unrecognized, source of supply. This is, however, a matter of comparatively little practical interest.

Manuring with mineral salts alone is unremunerative, and it is only the different effects on quality, if any, of different forms of nitrogenous manures, alone or in combination with minerals, that need be considered.

Do artificial nitrogenous manures over an average of years give better malting quality than natural manures? Or, to put the question somewhat differently, but more practically: Is it probable that top-dressings on barley, where (as after another white-straw crop) some help is required to obtain a full yield, give, generally speaking, better results in respect of quality than are likely to be got from the unexhausted residue of excrementitious animal matters remaining in the soil?

It is highly probable that the answer will depend on the character of the soil. What is really needed is a series of trials extending over several rotations on different soils, in which the quality of the grain grown after a corn crop with top-dressings should be compared with the quality grown after the roots fed off without added manure for the barley crop. These are in practice the two sets of conditions to which most interest attaches.

All that we can deduce from the Rothamsted experiments as bearing on this question is obtainable from a comparison between the farmyard manure plot and those plots treated with either ammonia salts or nitrate, and full minerals. And this comparison is not on all-fours with a comparison between effects of unexhausted residues from fed-off roots in rotation and similar artificial supplies to those used at Rothamsted. Still, as an absolute demonstration, it is the best available. It proves this much for soils like that at Rothamsted: that over-supply of organic nitrogen-containing matter in the soil is bad for malting quality, and that at least an equal quantity of grain with much better average quality can be got from top-dressings of artificials when the nitrogen supplied by the artificials is adequate in amount and accompanied with the needful minerals. If cost of manure is taken into consideration, the comparatively simple dressing of nitrate of soda and superphosphate (as on plot 2–AA) shows the best results over the whole period of these Rothamsted experiments.

It is probable that a smaller annual dressing than fourteen tons per acre of farmyard manure would have shown better

quality, though doubtless less quantity, than is given by plot 7–2. Plot 7–1, which was part of the undivided plot 7 until 1871, receiving previously the full farmyard manure dressing, and which has had nothing since 1871, is now (1895), generally speaking, yielding barley of better malting quality than the other half-plot, but the fall in crop was very rapid after 1871. In 1872 the drop was only five-eighths of a bushel per acre; but in 1873 it was six and three-quarter bushels; in 1874 eighteen bushels, and for the average of the following twenty years about the same. The higher value of the grain on this half of the plot in 1895, when it was especially marked, was undoubtedly due to better maturation, and it is highly probable that this would hold good in most years. The ratio of grain to straw is much better than on the continuously manured plot, and the lesser weight of straw in proportion to grain has doubtless allowed of harvesting under better conditions.

After this, perhaps too long drawn, survey of the results of the Rothamsted plots, there remains on the mind very strongly the impression that the effect of various manurial conditions on the quality of barley depends chiefly on the effect which those conditions have on the maturation of the grain. Whether or not manurial conditions which lead to a substantial increase in quantity will, in addition to such increase, improve maturation, or the reverse, depends much on atmospheric conditions. A light crop on a partially exhausted soil with bright but not too quick-ripening conditions may give excellent quality, or it may with too rapid maturing conditions 'go off' whilst still immature, and be both steely and husky. On the other hand, a heavy crop on a soil with full or over-full supply of plant food may, just by reason of its weight, suffer severely during maturation. There is little to choose in value per quarter between the grain of the ten-bushel crop on the unmanured and the fifty-bushel crop on the farmyard manure plots at Rothamsted in 1894, although the low value is due to different defects.

It is generally admitted that barley after wheat (and not top-dressed) is smaller in grain than after roots fed off, on soil of the same character. It is, however, almost always more 'kindly'. On the other hand, we are told by Mr. Cary Coles, of Winterbourne Stoke, Wilts (on whose farm two of

the series of barley trials of the Bath and West of England Society were carried out), that his experience is that barley of good quality, both as to size and kindliness, is generally grown after mangel *carted off*. For mangel there is customarily good preparation as to nitrogen supply, and also generally full mineral manuring, thus leaving for the barley more available phosphates than will be the case after wheat following roots, with sufficient available nitrogen. These seem to be conditions—and they are confirmed by the Rothamsted results—conducing to good quality, and the indication is that top-dressings for barley should give enough nitrogen and plenty of soluble phosphates.

Summary of Manurial Effects on continuously grown Barley

The more important points demonstrated in this survey are: (1) There was a manifest deterioration in quality where phosphates had been withheld for many years. (2) Addition of potash, soda and magnesia salts seemed to have little effect on quality at Rothamsted; where, however, ammonia salts were added with superphosphate but without potash, there was after many years a deterioration in quality. This was not seen, or only very slightly, where nitrate of soda and superphosphate were used without potash, and the difference may be due to the fact, demonstrated by Sir J. Henry Gilbert, that in the absence of added potash the barley plant takes up more soda from the soil, which would be supplied by the nitrate of soda and not by the ammonia salts. Professor Maercker, formerly of the University of Halle, found excellent results to follow potash manuring for barley in Germany. He mentions incidentally that barley is in that country frequently alternated with sugar-beet. This plant takes up much potash, which is all removed, and not, as with our root crops, for the most part returned to the soil. So that under these conditions potash manuring is obviously indicated as desirable. (3) The farmyard manure plot (14 tons per acre every year), whilst giving very heavy yields of both straw and grain, gives grain of coarse quality. (4) Ammonia salts or nitrate of soda used alone give poor results, both as to quality and quantity. (5) Ammonia salts, with super-

phosphate, gave good results for many years, but, as before stated, both yield and quality fell off in the latter years; where potash was also added yield and quality have both been very good throughout. (6) Nitrate of soda gave good results when superphosphate was added, and the further addition of potash did not improve the crop perceptibly.

Although the quality of the grain on these 'continuous' plots shows considerable differences due to the manures, and although these have been fairly constant year after year over the period taken as between the different plots, the extent of the divergence is slight in some years, and speaking generally is far less than between the grain grown on the same plots in different seasons. That is to say, notwithstanding the extreme exhaustion of some plots and the great accumulation in others, the weather has far more to do with the size and the maturation of the grain than the cumulative effects of fifty years of manurial treatment.

Briefly, the conclusion arrived at by the investigation of the Hoosfield material is that, subject to good atmospheric conditions, all the evidence points to sufficient, but not excessive, nitrogen supply and abundance of readily assimilable phosphates as the best manurial conditions; and this is in harmony with general experience.

CHAPTER XXI

INVESTIGATIONS ON ROTHAMSTED (AGDELL FIELD) BARLEY

A MORE complete investigation was carried out by Munro and myself on the samples of barley from Agdell Field plots. The soil is similar to that of Hoosfield—loam with clay sub-soil. The barley grown was that of the Chevalier type. These experiments were made in order to determine the influence of rotations and manures (and of both combined) on the quality of barley.

Arrangement of the Rotation Plots

The system adopted was the Norfolk rotation, viz., roots, barley, clover (or beans), wheat. The roots preceding the barley were carted on one set of plots and fed,[1] or cut up and spread, on another, and there was a complete duplicate set of plots where the land was fallowed after barley instead of going into clover or beans. We have therefore four variations in the rotation [2] :

F. Cl. Roots FED, Barley, CLOVER (or Beans), Wheat.
C. Cl. Roots CARTED, Barley, CLOVER (or Beans), Wheat.
F. Fa. Roots FED, Barley, FALLOW, Wheat.
C. Fa. Roots CARTED, Barley, FALLOW, Wheat.

There is not merely one, but three series of rotation plots, each of which has since 1848 consistently received *different manurial treatment.* The first series of four plots has been unmanured since the commencement (1848) of the experiment; the second series has had mineral manures only; superphosphate for the first eight rotations, that is, from 1849 to 1881 inclusive—and superphosphate with potash and other salts since; the third series has had the same minerals with

[1] As manurial effects are involved added food is inadmissible, and owing to this and the condition of the land it has frequently been found necessary to cut up and spread the roots instead of feeding them. This qualification is to be understood wherever 'FED' roots are referred to.

[2] F. denotes Fed. Cl. Clover. C. Carted. Fa. Fallow.

a rather heavy dressing of nitrogenous manure, viz., 200 lbs. ammonia salts, and, since the first course, 2,000 lbs. rape cake. The manures were all applied to the root crop preceding the barley, and the other crops were unmanured. Thirteen full rotations have now been completed, the thirteenth barley crop having been taken in 1897, and 1900 was the commencement of the fourteenth rotation with roots. There have been therefore, in the period we are dealing with, thirteen crops of barley on twelve different plots, or 156 in all. These 156 samples constitute the most interesting and instructive set of barley samples in existence anywhere.

AGDELL FIELD, ROTHAMSTED, ROTATION PLOTS

SERIES 1.—*No manures since* 1847

1. Roots FED 2. Barley 3. CLOVER (or Beans) 4. Wheat (1 F. Cl.)	1. Roots FED 2. Barley 3. FALLOW 4. Wheat (1 F. Fa.)
1. Roots CARTED 2. Barley 3. CLOVER (or Beans) 4. Wheat (1 C. Cl.)	1. Roots CARTED 2. Barley 3. FALLOW 4. Wheat (1 C. Fa.)

SERIES 2.—*Mineral manures only* (*superphosphate only* 1848–80, *superphosphate and potash and other salts since*) *applied to turnip crop in each rotation*

1. Roots FED 2. Barley 3. CLOVER (or Beans) 4. Wheat (2 F. Cl.)	1. Roots FED 2. Barley 3. FALLOW 4. Wheat (2 F. Fa.)
1. Roots CARTED 2. Barley 3. CLOVER (or Beans) 4. Wheat (2 C. Cl.)	1. Roots CARTED 2. Barley 3. FALLOW 4. Wheat (2 C. Fa.)

SERIES 3.—*Mineral manures as Series 2, and ammonia salts and rape cake (equal to 141 lbs. nitrogen) applied to root crop in each rotation*

1. Roots FED 2. Barley 3. CLOVER (or Beans) 4. Wheat (3 F. Cl.)	1. Roots FED 2. Barley 3. FALLOW 4. Wheat (3 F. Fa.)
1. Roots CARTED 2. Barley 3. CLOVER (or Beans) 4. Wheat (3 C. Cl.)	1. Roots CARTED 2. Barley 3. FALLOW 4. Wheat (3 C. Fa.)

From 1905 the twelve plots were reduced to six.

After a preliminary examination of all the samples we excluded altogether the samples of the first barley year, 1849. This left twelve samples for each of the twelve plots—144 in all—representing differences in manuring and other soil conditions.

We further reduced them to one-fourth, viz., 36, by making in the case of each plot three *average* samples, representing the earlier, middle and later four rotations respectively. We had thus three samples for each of the twelve plots, the first representing the years 1853, 1857, 1861, 1865; the second 1869, 1873, 1877, 1881; and the third 1885, 1889, 1893 and 1897.

The samples grown on the different plots in the first barley year of the experiment (1849), and not included in the average samples, are all very uniform in appearance. The colour is remarkably good considering the age of the grain. The samples have been so well preserved that no one would suppose from their appearance that they were more than a few years old.

Tables XX, XXII and XXIV give the Rothamsted record of each plot for each of the rotation barley years separately. The last column (7) requires explanation, and we have hesitated considerably before inserting it, on account of possible misconstructions. The barleys of the last rotation were valued at Rothamsted by Mr. Hewlins of St. Ives, and

TABLE XX.—Agdell Field, Rothamsted. Barley of First Four Rotations, 1853, 1857, 1861, 1865

1 Rotation	2 Barley years	3 Weight of roots fed or carted before barley	4 Bushels per acre dressed grain	5 Weight per bushel	6 Total grain to 100 total straw	7 Relative value per quarter	8 Plot
SERIES 1.—*Roots unmanured*							
		cwts.		lbs.		s. d.	
1. Roots CARTED. 2. Barley. 3. FALLOW. 4. Wheat	1853	37	32	52·6	85·0	28 6	1 C. Fa.
	1857	45½	43¾	53·8	105·0	27 0	
	1861	1¾	35½	54·8	94·0	27 6	
	1865	7½	34½	51·5	100·2	24 6	
Average	..	23	36½	53·2	96·0	26 10	
1. Roots FED. 2. Barley. 3. FALLOW. 4. Wheat	1853	27¼	33	52·7	88·3	28 0	1 F. Fa.
	1857	34	44¼	53·8	102·2	27 6	
	1861	1½	33	54·5	91·8	27 6	
	1865	9	35⅛	52·4	104·3	25 6	
Average	..	18	36¼	53·3	96·6	27 1	
1. Roots CARTED. 2. Barley. 3. CLOVER, 1850 (Beans, 1854, 1858, 1862). 4. Wheat	1853	26	34⅜	52·0	83·7	27 6	1 C. Cl.
	1857	32	48½	54·5	105·3	27 0	
	1861	1	38¾	54·3	87·1	27 6	
	1865	8¾	39	50·6	94·1	24 0	
Average	..	17	40⅛	52·8	92·5	26 6	
1. Roots FED. 2. Barley. 3. CLOVER, 1850 (Beans, 1854, 1858, 1862). 4. Wheat	1853	19½	28⅞	52·4	83·7	27 0	1 F. Cl.
	1857	20¼	40⅛	53·6	97·1	27 0	
	1861	1	29½	54·0	84·5	27 6	
	1865	8½	27¾	52·0	102·8	24 0	
Average	..	12	31½	53·0	92·0	26 4	
SERIES 2.—*Roots manured with superphosphate only*							
1. Roots CARTED. 2. Barley. 3. FALLOW. 4. Wheat	1853	256¾	32	52·8	93·4	27 6	2 C. Fa.
	1857	170½	30¾	54·1	111·8	28 6	
	1861	33¾	32⅜	55·0	94·9	28 0	
	1865	52¾	31¼	52·2	110·1	25 6	
Average	..	128	31⅜	53·5	102·5	27 4	
1. Roots FED. 2. Barley. 3. FALLOW. 4. Wheat	1853	273¼	39⅞	51·7	87·6	27 0	2 F. Fa.
	1857	193¾	48¾	54·0	105·3	29 0	
	1861	40¾	40¼	55·0	94·1	28 6	
	1865	79½	39	52·2	101·8	25 6	
Average	..	147	41⅛	53·2	97·4	27 6	

TABLE XX—*continued*

1 Rotation	2 Barley years	3 Weight of roots fed or carted before barley	4 Bushels per acre dressed grain	5 Weight per bushel	6 Total grain to 100 total straw	7 Relative value per quarter	8 Plot
SERIES 2.—*Roots manured with superphosphate only (continued)*							
		cwts.		lbs.		s. d.	
1. Roots CARTED. 2. Barley. 3. CLOVER, 1850 (Beans, 1854, 1858, 1862). 4. Wheat	1853	223¼	28¾	52·7	90·0	27 0	2 C. Cl.
	1857	136	28½	54·1	108·5	28 0	
	1861	29¼	30¾	54·9	88·8	28 0	
	1865	68	33¼	52·3	110·1	27 0	
Average	..	114	30¼	53·4	99·4	27 6	
1. Roots FED. 2. Barley. 3. CLOVER, 1850 (Beans, 1854, 1858, 1862). 4. Wheat	1853	250¼	37⅞	52·0	83·5	26 6	2 F. Cl.
	1857	196	52½	54·1	106·5	28 6	
	1861	38¾	42½	55·0	95·2	28 0	
	1865	78¾	41¼	51·9	98·6	24 6	
Average	..	141	43½	53·2	95·9	26 10	
SERIES 3.—*Roots manured with mixed minerals and nitrogenous manures*							
1. Roots CARTED. 2. Barley. 3. FALLOW. 4. Wheat	1853	408¼	37¾	53·0	86·8	26 6	3 C. Fa.
	1857	328¼	47½	54·8	112·1	28 6	
	1861	87½	60¾	55·0	89·3	28 6	
	1865	182½	44⅝	52·9	100·2	25 6	
Average	..	251	47⅝	53·9	97·1	27 3	
1. Roots FED. 2. Barley. 3. FALLOW. 4. Wheat	1853	390¾	37	51·2	70·7	25 0	3 F. Fa.
	1857	339¼	66⅝	54·3	103·4	28 0	
	1861	87	57¾	55·0	80·9	28 0	
	1865	185½	46½	51·6	75·7	24 0	
Average	..	250	51⅞	53·0	82·7	26 3	
1. Roots CARTED. 2. Barley. 3. CLOVER, 1850 (Beans, 1854, 1858, 1862). 4. Wheat	1853	396½	38¼	52·6	87·1	26 0	3 C. Cl.
	1857	333¾	48	54·6	112·2	28 0	
	1861	87½	60¾	54·8	87·6	28 0	
	1865	176¼	47½	53·0	98·4	25 0	
Average	..	248	48¼	53·7	96·3	26 9	
1. Roots FED. 2. Barley. 3. CLOVER, 1850 (Beans, 1854, 1858, 1862). 4. Wheat	1853	386	35¼	51·5	74·3	24 6	3 F. Cl.
	1857	341¼	63⅛	54·5	103·5	27 6	
	1861	72	54⅜	55·3	81·4	27 6	
	1865	168½	43⅜	52·2	79·5	24 0	
Average	..	242	49⅛	53·4	84·7	25 10	

Mr. Few of Cambridge, and the figures given for these years are theirs. For the figures attached to the other years we are alone responsible. It seemed difficult in any other way than by pricing the samples to indicate their general quality, but it will be readily understood that it is not an easy task to 'value' barleys grown in 1853, and at intervals of four years since. The samples were dried when they were originally put up, in order to preserve them, and they have been preserved in airtight bottles, most of which have never been opened from the time they were originally sealed up. They have doubtless altered somewhat in appearance from lapse of time. However, having been kindly given every possible facility for examining them in the sample-house at Rothamsted, we found that there still were distinct differences of quality observable between the samples.

It is almost needless to say that the values are not intended to be any other than comparative, and that they have no relation to the market values in the years of growth. Moreover, we are not prepared to justify the valuation as between different years. There is a strong likeness, as would be expected, between the twelve samples of each year in respect of colour and general appearance. But as between the samples of different years there is, of course, the widest difference in general character, differences which in ordinary practice do not confront a buyer or a seller. For instance, the barley of 1885 is all bright in colour; that of 1889 is all weathered; whether the average difference amounts to between 4s. and 5s., as we have estimated, or to more or less than this, is a matter on which opinions would probably vary greatly. Only an approximation could be attempted in respect of comparative values in different years. What was done was to fix a price for one sample in each year and to value the others of the same year up or down from that. If the values as between the barley of the different plots are fairly comparative in each year, then the averages of these values will be comparative also, and as our purpose here is to compare plot with plot, rather than year with year, this is all that is required. We may add that the values were all assessed before any other determinations were made upon the samples.

Characteristics of different seasons: first period, 1853, 1857, 1861, 1865

1853

The barley of this year is of very different character from that of 1849, much smaller, dingy, and washed. Weight per bushel very low, 51 to 53 lbs. Much more difference in quality between plots than in 1849, but little difference in yield considering that on Series 3 crops of 19 to 20 tons of roots had been grown, whilst on Series 1 there were less than 2 tons. Neither effects of manuring for the roots nor of feeding and carting have much influence on yield of grain, although the feeding of heavy root crop gives much more straw. There was a very wet July unfavourable to grain formation.

1857

A record year in respect of yield. After fed roots fully manured, the extraordinary crop of 66⅝ bushels was grown, the highest ever given by any plot. Quality is above the average of the four years, and better on the high-yielding plots fully manured for roots than on the others. Very high yield and fair quality for once go together. The grain is not plump or heavy, but it is very well matured, especially on the high-yielding plots. A season favouring land in good heart during the vegetative period, and also specially favourable at the time of grain formation, for notwithstanding very heavy straw there was a very high ratio of grain to straw. A table given by Sir Henry Gilbert[1] shows that there was a mild and rather dry spring, followed by a very hot summer and early harvest.

1861

With all the twelve different preparations for the crop there was little difference in quality although great difference in yield. The root crop of 1860 was nearly a failure on all the plots, and the differences in yield are due to manurial residues, but the quality on every plot was evidently influenced mainly by the season. It was all large and heavy but coarse, badly matured grain.

[1] *Lawes Agricultural Trust Lectures*, U.S. Dept. Agric., p. 73.

1865

The preceding root crop was again poor. The barley was over-average yield on all plots, but harvesting conditions affected both yield and quality considerably, for all the grain was badly weathered—'over-matured' in fact. It was small, uneven, and light; altogether of lower value than that of any of the other twelve barley years. A backward spring succeeded by very hot weather and excessive rainfall, not good for grain formation, and a wet harvest spoilt the crop.

Tables XX, XXII and XXIV, which give the full records relating to the produce on each plot in each year, are too complex to be commented on in detail and are inserted mainly for purposes of reference. Table XXI, p. 201, gives for each plot separately the averages, for the first four rotation barley crops, of the recorded figures relating to produce, also the averages of the relative money valuations, and in the last three columns the determinations which we made upon the average samples of the twelve plots. These are:

1. Weight in grammes of 1,000 grains, affording comparison in respect of size of grain.
2. Percentage of 'mealy' grains, i.e. grains which when cut show white fractures, indicating the degree of maturation.
3. Percentage of total nitrogen,[1] which will be found to vary with great regularity with the 'maturation' in the samples of the same years. The more fully matured the grain the lower is the relative nitrogen content in barley of the same years. Barleys of different years cannot be so compared, as will be seen by contrasting Table XXI with Table XXIII, p. 209, in respect of this relation.

During the four years summarized in Table XXI the yield of grain on the unmanured plots is remarkably well

[1] These percentages have not been worked out to percentage of 'dry matter of the grain'; but as the samples of the same year have all been dried and preserved alike this will not affect the value of the determinations for comparative purposes. The moisture content of the various samples is about 10 per cent., and does not vary appreciably, as we have satisfied ourselves from a number of moisture determinations.

TABLE XXI.—Agdell Field, Rothamsted, Rotation Plots. Averages of Four Barley Years, 1853, 1857, 1861, 1865

Manures applied to roots	Roots fed or carted	Fallow or clover after barley	Weight of roots fed or carted before barley	Bushels per acre dressed grain	Weight per bushel	Total grain to 100 total straw	Relative value per quarter, four years' average	Weight per 1,000 corns of average sample	Mealy corns per 100 of average sample	Total nitrogen per cent. of average sample	Plot
			cwts.		lbs.		s. d.	grms.			
SERIES 1 None	Carted	Fallow	23	36½	53·2	96·0	26 10	46·5	61	1·41	1 C. Fa.
	Fed	Fallow	18	36¼	53·3	96·6	27 1	47·1	64	1·39	1 F. Fa.
	Carted	Clover	17	40⅛	52·8	92·5	26 6	46·8	62	1·46	1 C. Cl.
	Fed	Clover	12	31½	53·0	92·0	26 4	46·3	54	1·48	1 F. Cl.
		Average	17	36⅛	53·1	94·3	26 8	46·7	60	1·43	
SERIES 2 Superphosphate only	Carted	Fallow	128	31⅜	53·5	102·5	27 4	45·6	69	1·33	2 C. Fa.
	Fed	Fallow	147	41⅛	53·2	97·4	27 6	46·4	69	1·32	2 F. Fa.
	Carted	Clover	114	30¼	53·4	99·4	27 6	46·4	71	1·34	2 C. Cl.
	Fed	Clover	141	43½	53·2	95·9	26 10	47·2	64	1·44	2 F. Cl.
		Average	132	36¼	53·3	98·8	27 10	46·4	68	1·36	
SERIES 3 Mixed minerals, ammonia salts and rape cake.	Carted	Fallow	251	47⅝	53·9	97·1	27 3	47·2	65	1·41	3 C. Fa.
	Fed	Fallow	250	51⅞	53·0	82·7	26 3	46·4	58	1·55	3 F. Fa.
	Carted	Clover	248	48¼	53·7	96·3	26 9	47·6	60	1·47	3 C. Cl.
	Fed	Clover	242	49⅛	53·4	84·7	25 10	46·8	49	1·61	3 F. Cl.
		Average	248	49¼	53·5	90·2	26 6	47·0	58	1·51	

TABLE XXII.—Agdell Field, Rothamsted. Barley of Second Four Rotations, 1869, 1873, 1877, 1881

1 Rotation	2 Barley years	3 Weight of roots fed or carted before barley	4 Bushels per acre dressed grain	5 Weight per bushel	6 Total grain to 100 total straw	7 Relative value per quarter	8 Plot
SERIES 1.—*Roots unmanured*							
		cwts.		lbs.		s. d.	
1. Roots CARTED. 2. Barley. 3. FALLOW. 4. Wheat	1869	nil	21¼	53·3	77·0	29 0	1 C. Fa.
	1873	51⅞	20¾	54·4	88·9	30 6	
	1877	31½	23	55·0	109·2	29 0	
	1881	32⅝	29⅛	54·3	103·7	26 6	
Average	..	29	23½	54·5	94·7	28 9	
1. Roots FED. 2. Barley. 3 FALLOW. 4. Wheat	1869	nil	21	52·6	72·5	29 0	1 F. Fa.
	1873	49¼	21	55·2	93·4	30 0	
	1877	32¼	22½	55·0	104·7	29 0	
	1881	38¼	31½	53·5	110·3	26 6	
Average	..	30	24	54·1	95·2	28 7	
1. Roots CARTED. 2. Barley. 3. CLOVER, 1874 (Beans, 1866, 1870, 1878). 4. Wheat	1869	nil	24⅝	52·8	72·4	28 0	1 C. Cl.
	1873	34⅛	23½	55·2	102·4	29 6	
	1877	17¼	23½	54·2	103·2	28 6	
	1881	14	26¾	52·6	96·9	25 6	
Average	..	16	24⅜	53·7	93·7	27 10	
1. Roots FED. 2. Barley. 3. CLOVER, 1874 (Beans, 1866, 1870, 1878). 4. Wheat	1869	nil	25⅝	52·3	74·2	29 0	1 F. Cl.
	1873	29½	23	54·6	90·2	29 0	
	1877	21	23¾	53·8	99·3	28 0	
	1881	21	26	54·3	99·6	27 6	
Average	..	18	24⅝	53·7	90·8	28 4	
SERIES 2.—*Roots manured with superphosphate only*							
1. Roots CARTED. 2. Barley. 3. FALLOW. 4. Wheat	1869	nil	25½	54·7	77·7	30 0	2 C. Fa.
	1873	142¼	22⅛	54·5	98·0	31 6	
	1877	193¼	21	54·5	118·6	31 6	
	1881	224	24¼	54·3	108·0	28 6	
Average	..	140	23¼	54·5	100·6	30 4	
1. Roots FED. 2. Barley. 3. FALLOW. 4. Wheat	1869	nil	30⅛	55·3	76·5	30 6	2 F. Fa.
	1873	167½	27	54·9	99·2	31 0	
	1877	208¼	31½	54·9	106·9	31 0	
	1881	238¾	28¼	55·0	105·5	29 6	
Average	..	153	29¼	55·0	97·0	30 6	

TABLE XXII—*continued*

1 Rotation	2 Barley years	3 Weight of roots fed or carted before barley	4 Bushels per acre dressed grain	5 Weight per bushel	6 Total grain to 100 total straw	7 Relative value per quarter	8 Plot
SERIES 2.—*Roots manured with superphosphate only* (*continued*)							
		cwts.		lbs.		s. d.	
1. Roots CARTED. 2. Barley. 3. CLOVER, 1874 (Beans, 1866, 1870, 1878). 4. Wheat	1869	nil	28¾	55·1	82·0	30 0	2 C. Cl.
	1873	170⅝	20¾	55·3	83·7	30 0	
	1877	188¼	24¼	54·8	117·8	30 6	
	1881	199½	24½	55·3	109·8	29 0	
Average	..	140	24½	55·1	98·3	29 10	
1. Roots FED. 2. Barley. 3. CLOVER, 1874 (Beans, 1866, 1870, 1878). 4. Wheat	1869	nil	33½	54·9	79·6	30 0	2 F. Cl.
	1873	190½	29½	55·0	94·2	31 6	
	1877	225¾	38⅜	55·2	108·5	30 0	
	1881	223¾	28¾	55·7	113·4	29 0	
Average	..	160	32½	55·2	98·7	30 1	
SERIES 3.—*Roots manured with mixed minerals and nitrogenous materials*							
1. Roots CARTED. 2. Barley. 3. FALLOW. 4. Wheat	1869	nil	39¾	56·1	76·7	29 0	3 C. Fa.
	1873	332	31½	54·9	109·8	31 0	
	1877	309¾	30¾	55·4	109·6	31 0	
	1881	450¼	33⅜	55·9	108·0	29 6	
Average	..	273	33⅞	55·6	101·0	30 0	
1. Roots FED. 2. Barley. 3. FALLOW. 4. Wheat	1869	nil	38¼	55·1	69·3	29 0	3 F. Fa.
	1873	331¼	47	55·2	95·9	31 0	
	1877	377¼	44¾	55·7	97·2	31 0	
	1881	447¼	48	56·1	91·1	30 0	
Average	..	289	44½	55·5	88·4	30 3	
1. Roots CARTED. 2. Barley. 3. CLOVER, 1874 (Beans, 1866, 1870, 1878). 4. Wheat	1869	nil	43	55·6	75·3	29 6	3 C. Cl.
	1873	339⅞	31¾	55·2	107·4	31 6	
	1877	356	34¾	55·5	102·8	31 0	
	1881	439½	35¼	55·9	108·2	30 0	
Average	..	284	36¼	55·5	98·4	30 6	
1. Roots FED. 2. Barley. 3. CLOVER, 1874 (Beans, 1866, 1870, 1878). 4. Wheat	1869	nil	42¼	56·1	76·6	28 6	3 F. Cl.
	1873	330	45⅛	55·8	95·9	30 0	
	1877	359¼	49⅛	55·7	90·8	30 0	
	1881	446¼	50¼	56·6	93·8	30 6	
Average	..	284	46¾	56·1	89·3	29 9	

maintained, and on the other plots well above the average. It is also higher than that of the first year, 1849. But the quality is very inferior in three out of the four years. The samples show what is so frequently seen, that with over-average yield there is little reason to hope for over-average quality, but rather the reverse, and that seasons which show the best return for expenditure in preparation are very often not those which give the finest grain. With wheat, good yield and good quality often go together; but there are two reasons why wheat and barley differ in this respect. Weight per bushel is generally a good criterion of the quality of wheat and this frequently goes along with good yield, but it is not to the same extent a criterion of the value of barley, and it is not so likely to go with high yield. The other obvious reason is that barley suffers more from adverse harvesting conditions, and a fortnight's bad weather is, in our climate, just as likely to supervene on a heavy as on a light crop, with much worse results to barley than to wheat.

The good effect of phosphates on quality, which is so plainly shown by the continuous barley plots at Rothamsted, is also apparent in the rotation crops of the four years now under consideration. The quality of grain on the four plots of Series 2, where only superphosphate has been applied to the preceding root crop, is distinctly better than that of the corresponding plots of Series 1, where no manure was used for the roots. There has been better grain formation, as is shown in increased ratio of grain to straw, and distinctly better maturation with less nitrogenous matter in the grain. The average weight per bushel and the size of the grain are practically the same on the three series of plots, but these are not, as we believe, data from which the malting quality of grain can be safely deduced.

It is evident that the lower quality on the unmanured plots is due to want of phosphates and not to lack of condition from non-supply of nitrogen, for if the latter were the case we should find that where the preceding root crop was much heavier than on the 'superphosphate only' plots, as it was on the plots of Series 3 with full nitrogenous and phosphatic manures, there would have been still better quality; but this is not the case, and the evidence is irresistible that the better quality of the barley on the plots where superphosphate only

was applied to the roots is due directly to the supply of soluble phosphates.

In these first four courses, then, the quality of the barley evidently did not suffer from exhaustion of nitrogen on the unmanured plots, but it did suffer from over-supply to the plots of Series 3. Here the residue from the heavy compound manuring where the roots were carted, and the still heavier residue where they were fed, gave a much greater yield of grain than where no nitrogenous manure was used, but the quality was distinctly inferior to that of Series 2, and little if any better than that of Series 1.

We will now consider the effect on the quality of the grain, as it appears to have been influenced by feeding and carting respectively. There is not much difference shown. Where the root crops have been heavy, as on Series 3, the 'roots-carted' plots give barley of better quality than the corresponding 'roots-fed' plots. The average difference amounts to perhaps 1s. per quarter in value, and is shown in the better maturation and lower nitrogen content. It is strange at first sight to find that in this series the 'roots-fed' plots three years out of the four give no higher yield than the 'roots-carted' plots. But all the crops are heavy, the lowest 37 and the highest 67 bushels per acre, and it would appear that in these four seasons the nitrogen supply was superabundant for grain formation. In each of the four seasons the straw was very much heavier on the 'fed' plots, and the ratio of grain to straw was lower than on the 'carted' plots. Both in 1857 and in 1861 the total produce (i.e. grain and straw) of the 'fed' plots of Series 3 was over 3 tons per acre, one of the two plots in 1861 yielding close on 2 tons of straw. On Series 2, with very fair but much lower yields (28 to 42 bushels per acre), in these four seasons there was hardly any perceptible difference in quality between the fed and carted plots. The root crops were generally 5 or 6 tons per acre lower on these plots than on those of Series 3, and there is no sign that the feeding of them supplied in any case more nitrogenous matter than the barley needed, either for quantity or quality. The differences in yield and quality of grain due to feeding as against carting roots on Series 1 (unmanured roots), where after the first course there was almost a complete failure of the root crop, will neither in these four seasons nor in the

following ones require consideration. On all these plots the land is practically unmanured fallow before the barley crop, and the only point to notice is that both yield and quality are the better for this previous fallowing, if it is possible to judge by comparison with the plot in the Hoosfield, where barley is grown year after year without manure.

Lastly, in respect of these four seasons, 1853, 1857, 1861, 1865, we have to consider the effect of clover or beans as against fallow in the rotation. Clover was sown with the barley in 1849, 1853, 1857 and 1861, but the last three crops failed, so in the following years (1854, 1858, 1862) and in 1866 beans were grown instead. Almost uniformly on all three series the inclusion of the leguminous crop in the rotation lowers somewhat the quality of the barley. The value of the leguminous crop in the rotation is of course out of comparison with the slight effect on the quality of the barley, and the point is only interesting as throwing light on the question of how far quality is affected by improved 'condition' of soil, due to the under-surface accumulation of nitrogen which the clover, at any rate, promotes.

Second period, 1869, 1873, 1877, 1881

1869

The barley of this year is rather small, generally heavy grain, somewhat hard but of good colour and shape, slightly grey, perhaps from weather conditions before cutting, still very useful grain of over-average value. The grain of Series 1, unmanured for roots, is smaller but rather mellower than that of the others. The differences in value of the various samples are slight, and there is, as is the case in almost every season, a certain uniformity of character or family likeness about all the twelve samples. The roots of the preceding year were a complete failure, and between the plots where they are usually carted or fed, respectively, there was no difference to speak of, either in yield or quality. The yield generally was about an average and the quality evidently was influenced far less by soil than by atmospheric conditions. There was a rather backward plant in the spring, followed by a summer dryer than average.

1873

Very shapely grain, generally well matured, and differences in quality, due to preparation, slight. There are this year great differences in yield between the plots following roots 'fed' and 'carted' respectively. The root crops had been good on the fully manured plots (16 to 17 tons) and the season favoured the effect of manuring and feeding on yield, without producing marked differences in quality. There was a fine growing July, favourable for grain formation, and maturation was fairly good.

1877

The grain is not unlike that of 1873 in character. Again the weight of the root crop and its disposal tells on the yield of the barley, and the quality is over-average with fair crops. The plots unmanured for roots, with consequent failure of that crop, show signs of exhaustion, not only in the yield but in smaller and more uneven grain. The proportion of grain to straw is very high on all the plots. It was an unfavourable season for vegetation, with a late harvest, and there were more differences than usual in quality, due to differences in preparation.

1881

There is again considerable difference in the quality of the barleys of the different plots. Previous manuring tells this year on weight of grain and quality generally. High yield and good quality go together, and the 50-bushel crops of plots, where over 20 tons of roots were fed the previous year, are fully 4s. a quarter better than those of the unmanured plots, distinctly better also than those of the superphosphate only plots, where the root crop was only half the weight. The best samples are shapely and well matured. The high ratio of grain to straw shows that this was a favourable season for grain formation.

The second period of sixteen years gives four barley crops, the quality of all of which is better than either of the previous four, although neither is quite equal to the first crop of all, that of 1849. The yields, however, are not so good even in the years when full manuring has given abundant root crops

preceding the barley. On the continuously unmanured plots, of course, the yield has fallen away, and varies on the four different plots in these four years from 20 to 25 bushels per acre; general exhaustion has told on the quality of the grain also, which in most years is inferior by 2s. per quarter to that of Series 2 and 3. On Series 2 (superphosphate only applied to the roots) the yields, as compared with the previous period, are not more reduced than on Series 3 (full manuring for the roots), which gives good crops ($38\frac{3}{8}$ to $50\frac{1}{4}$ bushels per acre), though not so heavy as the exceptional ones of the previous period. The effect of the phosphates on quality continues to be clearly shown, for, notwithstanding the obvious nitrogen exhaustion, the samples of Series 2 are on the average fully equal to those of Series 3. The wholly different character of the four (1869–73–77–81) seasons from that of the previous four (1853–57–61–65) is most plainly shown in the quality of the barley on the plots of Series 3, the later seasons having favoured grain formation to a much greater extent than vegetation. Putting the four plots of this series together, the ratio of grain to straw in the later years was distinctly better (94·3 of grain to 100 straw, against 90·2), and we estimate the quality of the grain to be between 3s. and 4s. a quarter better accordingly. Table XXIII, on the next page, shows these points in greater detail.

The plots where clover or beans are grown after the barley show the same relations, in respect of the quality of the grain, to those fallowed after barley as have been already noted. In three out of the four rotations the crop succeeding the barley was beans. Clover was sown with the barley only in 1873. It gave three cuttings in the following year, and the effect of the undoubtedly improved 'condition' of the land is very manifest in much better yield in 1877; the yield is from 3 to 7 bushels more on the clovered plots of Series 2 and 3 than on the corresponding fallowed plots. The grain is larger and heavier, but the maturation is generally perceptibly lower.

Third period, 1885, 1889, 1893, 1897

1885

If we leave out of account, as we shall now do, the quality of the grain on the plots where no manure has been applied

TABLE XXIII.—Agdell Field, Rothamsted, Rotation Plots. Averages of Four Barley Years, 1869, 1873, 1877, 1881

Manures applied to roots	Roots fed or carted	Fallow or clover after barley	Weight of roots fed or carted before barley	Bushels per acre dressed grain	Weight per bushel	Total grain to 100 total straw	Relative value per quarter, four years' average	Weight per 1,000 corns of average sample	Mealy corns per 100 of average sample	Total nitrogen per cent. of average sample	Plot
			cwts.		lbs.		s. d.	grms.			
SERIES 1 None	Carted	Fallow	29	$23\frac{1}{2}$	54·3	94·7	28 9	43·0	68	1·26	1 C. Fa.
	Fed	Fallow	30	24	54·1	95·2	28 7	43·9	69	1·22	1 F. Fa.
	Carted	Clover	16	$24\frac{3}{8}$	53·7	93·7	27 10	45·6	53	1·34	1 C. Cl.
	Fed	Clover	18	$24\frac{5}{8}$	53·7	90·8	28 4	45·5	55	1·32	1 F. Cl.
		Average	$23\frac{1}{4}$	$23\frac{1}{8}$	54	93·6	28 4	44·5	61	1·28	
SERIES 2 Superphosphate only	Carted	Fallow	140	$23\frac{1}{4}$	54·5	100·6	30 4	42·7	78	1·13	2 C. Fa.
	Fed	Fallow	153	$29\frac{1}{4}$	55	97	30 6	43·8	76	1·19	2 F. Fa.
	Carted	Clover	140	$24\frac{1}{2}$	55·1	98·3	29 10	44·0	67	1·24	2 C. Cl.
	Fed	Clover	160	$32\frac{1}{2}$	55·2	98·7	30 1	45·0	64	1·27	2 F. Cl.
		Average	148	$27\frac{1}{2}$	54·9	98·6	30 2	43·9	71	1·22	
SERIES 3 Mixed minerals, ammonia salts and rape cake.	Carted	Fallow	273	$33\frac{7}{8}$	55·6	101	30 1	44·8	76	1·26	3 C. Fa.
	Fed	Fallow	289	$44\frac{1}{2}$	55·5	88·4	30 3	46·2	64	1·34	3 F. Fa.
	Carted	Clover	284	$36\frac{1}{4}$	55·5	98·4	30 6	45·6	70	1·30	3 C. Cl.
	Fed	Clover	284	$46\frac{3}{4}$	56·1	89·3	29 9	46·2	62	1·41	3 F. Cl.
		Average	262	$40\frac{3}{8}$	55·7	94·3	30 2	45·7	66	1·33	

for nearly forty years, the grain of 1885 is of better quality than that of any previous year. One sample, especially that of the plot 3 F. Fa. (fed roots before, and fallow after, barley), is better than any other sample of the whole fifty years. The grain on all the plots is very bright in colour and generally of very good appearance, with considerable variations, however, and much better on the plots following fed roots than on those where the produce was carted off. The yield of the different plots also varies greatly, only one plot, 3 F. Cl. (fed roots before, and clover following, the barley), giving anything like a full crop, viz., 44¾ bushels. This is 12 bushels more than 3 F. Fa. above referred to, but the quality on the clovered plot is a good 3s. per quarter lower. Contrary to what was generally the case in previous years, a season which has given good quality of grain has given a very low ratio of grain to straw. Not that the bulk of straw on the ground has been heavy, but that the grain has been, though well formed and of over-average quality, still more deficient in quantity. All the different conditions as to preparation tell considerably, and consistently with each other. The feeding of the roots, which were about average crops (14 to 15 tons on Series 3, and 7 to 10 tons on Series 2), as against the carting of them, improves both quantity and quality of produce on both series of plots. The effect of previous clover in the rotation is still more marked, almost doubling the yield in some cases, but with lower quality, except in the case of one pair of plots, viz., 2 C. Fa. (carted roots, barley, fallow) and 2 C. Cl. (carted roots, barley, clover). The quality on the latter plot as well as the yield is slightly the better of the two. It is noteworthy that this exception to the general effect of the leguminous crop in the rotation on the quality of the barley, which appeared for the first time in the 1881 crop, is repeated in subsequent rotations. It would seem as if where superphosphate only and no nitrogen is applied as manure, and the roots are carted off the land, the effect of the nitrogen accumulation of the clover crop is ultimately beneficial to quality. In 1885 there was a cold, wet and backward spring, unfavourable for a good plant, but a dry warm summer and early harvest.

1889

A bad barley year. The crop was one of the worst in respect of yield, and nearly the worst in quality of the whole fifty years. Even where over 20 tons of roots were fed off there was not more than 26⅝ bushels of grain. Low weight per bushel, bad colour due to very unfavourable harvest conditions, and rough, uneven appearance are the consequences of a season which levelled down all the previous preparation to an all-round unsatisfactory result.

1893

Except that the grain is less weathered than that of 1889, there is little to choose between the two years. The yield is even worse than in 1889, and the grain is coarser and worse matured. The 'fed' root plots are slightly better than the 'carted', and fallowing again gives better grain than where beans were grown in the last rotation. There was a very dry spring and a very wet July. The season is clearly responsible for a poor plant and poor grain formation, so that with little straw there is (in proportion) still less grain, and, finally, unfavourable conditions for maturation.

1897

Another unsatisfactory barley year, but with redeeming features not present in the two previous ones. The effects of the preparation of the previous year, viz., fed and carted roots respectively, are seen in the yields, for whilst the 'carted' root plots give generally lower yields even than in 1893, on the plot 3 F. Cl., where a fully manured and heavy crop of roots was fed, and where there was clover in the rotation (that is to say, where the conditions conformed most closely to general practice), there was harvested nearly double the crop grown in 1893, viz., 42¼ bushels in 1897 as against 25½ bushels in 1893, and that, moreover, of several shillings per quarter better value. The harvesting conditions, however, were very adverse, and whilst the grain was well enough matured on some of the plots, it was more or less weathered before it could be got together. It was a season when, with good preparation, there was before harvest the promise of

TABLE XXIV.—Agdell Field, Rothamsted. Barley of Third Four Rotations, 1885, 1889, 1893, 1897

1 Rotation	2 Barley years	3 Weight of roots fed or carted before barley	4 Bushels per acre dressed grain	5 Weight per bushel	6 Total grain to 100 total straw	7 Relative value per quarter		8 Plot
SERIES 1.—*Roots unmanured*								
		cwts.		lbs.		s.	d.	
1. Roots CARTED. 2. Barley. 3. FALLOW. 4. Wheat	1885	$17\frac{7}{8}$	$15\frac{1}{2}$	54·5	58·3	28	0	1 C. Fa.
	1889	15	$15\frac{1}{2}$	52·7	87·7	25	0	
	1893	$9\frac{7}{8}$	$19\frac{7}{8}$	55·8	72·5	26	6	
	1897	$15\frac{1}{4}$	$11\frac{1}{4}$	51·4	70·5	30	6	
Average	..	14	$15\frac{5}{8}$	53·6	72·2	27	6	
1. Roots FED. 2. Barley. 3. FALLOW. 4. Wheat	1885	$20\frac{1}{4}$	$22\frac{3}{4}$	54·6	72·9	29	0	1 F. Fa.
	1889	23	$16\frac{7}{8}$	52·2	90·6	25	6	
	1893	$12\frac{3}{8}$	19	55·5	68·3	26	6	
	1897	$24\frac{1}{2}$	$13\frac{1}{8}$	51·3	68·0	31	0	
Average	..	20	18	53·4	75·0	28	0	
1. Roots CARTED. 2. Barley. 3. CLOVER (Beans, 1890). 4. Wheat	1885	5	$12\frac{1}{8}$	50·8	54·3	26	0	1 C. Cl.
	1889	$2\frac{1}{4}$	11	51·0	62·2	24	0	
	1893	$6\frac{3}{4}$	$16\frac{7}{8}$	55·3	69·8	26	0	
	1897	$7\frac{1}{4}$	$11\frac{1}{2}$	51·3	54·0	29	0	
Average	..	5	$12\frac{3}{4}$	52·1	60·0	26	3	
1. Roots FED. 2. Barley. 3. CLOVER (Beans, 1890). 4. Wheat	1885	12	16	51·3	62·1	27	6	1 F. Cl.
	1889	8	$12\frac{5}{8}$	51·4	76·9	24	6	
	1893	$6\frac{1}{4}$	$14\frac{1}{4}$	55·8	63·9	26	0	
	1897	$11\frac{1}{4}$	$11\frac{3}{4}$	51·7	70·1	29	0	
Average	..	9	$13\frac{5}{8}$	52·5	68·2	26	9	
SERIES 2.—*Roots manured with superphosphate and other minerals*								
1. Roots CARTED. 2. Barley. 3. FALLOW. 4. Wheat	1885	$159\frac{3}{4}$	$12\frac{7}{8}$	53·7	75·8	29	0	2 C. Fa.
	1889	$142\frac{3}{4}$	$15\frac{1}{8}$	52·6	83·9	26	0	
	1893	$226\frac{1}{8}$	13	55·8	66·1	27	6	
	1897	161	$12\frac{1}{4}$	52·1	73·0	31	0	
Average	..	172	$13\frac{1}{8}$	53·5	74·7	28	4	
1. Roots FED. 2. Barley. 3. FALLOW. 4. Wheat	1885	$172\frac{1}{2}$	$17\frac{1}{8}$	55·3	74·1	32	6	2 F. Fa.
	1889	166	$19\frac{1}{4}$	52·5	98·1	26	0	
	1895	$263\frac{1}{8}$	$15\frac{3}{4}$	56·0	73·5	28	0	
	1897	$177\frac{1}{4}$	$19\frac{3}{4}$	52·2	77·6	32	0	
Average	..	194	18	54·0	80·8	29	7	

TABLE XXIV—*continued*

1 Rotation	2 Barley years	3 Weight of roots fed or carted before barley	4 Bushels per acre dressed grain	5 Weight per bushel	6 Total grain to 100 total straw	7 Relative value per quarter	8 Plot
SERIES 2.—*Roots manured with superphosphate and other minerals* (*continued*)							
		cwts.		lbs.		s. d.	
1. Roots CARTED.	1885	173¼	19⅞	53·9	76·1	29 6	2 C. Cl.
2. Barley. 3. CLOVER	1889	207	21¾	53·3	96·7	26 0	
(Beans, 1890).	1893	202⅝	15⅞	56·0	71·4	27 0	
4. Wheat	1897	215½	22½	53·4	71·2	33 0	
Average	..	200	20	54·1	78·8	28 9	
1. Roots FED.	1885	206	32½	55·8	77·8	31 6	2 F. Cl.
2. Barley. 3. CLOVER	1889	249¼	29¾	53·8	101·5	26 6	
(Beans, 1890).	1893	254½	19⅝	57·0	82·6	28 0	
4. Wheat	1897	240¾	37¾	53·9	76·0	33 6	
Average	..	238	29⅞	55·1	84·5	29 10	
SERIES 3.—*Roots manured with mixed mineral and nitrogenous manures*							
1. Roots CARTED.	1885	298¼	19	55·2	73·0	32 6	3 C. Fa.
2. Barley. 3. FALLOW.	1889	431¼	20	52·4	91·9	26 6	
4. Wheat	1893	523⅛	18⅝	57·2	72·5	28 6	
	1897	345	21¼	52·7	80·2	32 0	
Average	..	399	19¾	54·4	79·2	29 10	
1. Roots FED.	1885	296¼	32¼	56·3	66·4	35 0	3 F. Fa.
2. Barley. 3. FALLOW.	1889	423¾	23½	53·1	71·5	27 0	
4. Wheat	1893	500¾	25⅞	57·1	80·2	28 0	
	1897	331½	35⅜	53·8	77·1	32 0	
Average	..	388	29¼	55·1	73·8	30 6	
1. Roots CARTED.	1885	286¾	34¾	55·8	79·8	32 0	3 C. Cl.
2. Barley. 3. CLOVER	1889	472¾	26⅝	53·7	86·0	27 0	
(Beans, 1890).	1893	473	20½	56·8	76·3	28 0	
4. Wheat	1897	343¼	30¼	54·2	75·5	32 0	
Average	..	394	28	55·1	79·2	29 9	
1. Roots FED.	1885	280¾	44¾	56·6	75·6	32 0	3 F. Cl.
2. Barley. 3. CLOVER	1889	417½	25½	53·4	67·9	26 0	
(Beans, 1890).	1893	333⅞	25½	57·1	75·9	27 6	
4. Wheat	1897	319¼	42¼	53·6	71·3	32 6	
Average	..	338	34½	55·2	72·7	29 6	

both good yield and good quality. On the exhausted plots there was never any promise of either, as is shown by the very poor yield (lower than that of any previous season in several of them), by the very low proportion of grain to straw, and by the very thin grain; but on the plots well prepared there was every promise of high quality as well as good yield, and notwithstanding the weathering of the grain it was on these plots of over-average quality. There was a wet spring. July was a good corn month, but rain came in the middle of harvest.

The last sixteen years of the period under review, with barley in the years 1885, 1889, 1893, 1897, would be expected to show more clearly than either of the two preceding crops the cumulative effect of high manuring for the root crop as against mineral manuring only, both where the roots are carted and where they are either fed, or cut up and spread on the land; and they would also be expected to show clearly the effect on 'condition' of soil and character of grain due to inclusion or exclusion of a leguminous crop (clover or beans) in the rotation. They should also demonstrate the character of the grain which will be grown on starved land, that is, where no manures are applied, and where the supposed 'restorative' crops alternating with the corn are necessarily either very poor or quite a failure. Although the seasons were none of them satisfactory for barley, considering yield and quality together, yet the above-mentioned points are all well illustrated.

The plots of Series 1, which at the end of the period had been unmanured for fifty years, give, it is true, more grain than would be expected, owing doubtless to the land on the plots being practically fallow (roots in one year out of four), but the quality has distinctly deteriorated both in respect of size of grain and of maturation. Whilst in the first four rotations the quality was on an average not more than 1s. a quarter lower than that of the superphosphate plots, and about equal to that of the fully manured plots, it is now at least 3s. worse than the latter, and very distinctly inferior to the former. There is not only deterioration due to seasons, but also still greater deterioration due to soil conditions, and it is clear from comparison with Series 2 that the inferiority of quality is due to the absence of phosphates.

Table XXV.—Agdell Field, Rothamsted, Rotation Plots. Averages of Four Barley Years, 1885, 1889, 1893, 1897

Manures applied to roots	Roots fed or carted	Fallow or clover after roots	Weight of roots fed or carted before barley	Bushels per acre dressed grain	Weight per bushel	Total grain to 100 total straw	Relative value per quarter, four years' average	Weight per 1,000 corns of average sample	Mealy corns per 100 of average sample	Total nitrogen per cent. of average sample	Plot
			cwts.		lbs.		s. d.	grms.			
Series 1 None	Carted	Fallow	14	$15\frac{5}{8}$	53·6	72·2	27 6	42·6	62	1·30	1 C. Fa.
	Fed	Fallow	20	18	53·4	75·0	28 0	43·1	68	1·19	1 F. Fa.
	Carted	Clover	5	$12\frac{3}{4}$	52·1	60·0	26 3	44·4	33	1·65	1 C. Cl.
	Fed	Clover	9	$13\frac{5}{8}$	52·5	68·2	26 9	44·3	45	1·54	1 F. Cl.
		Average	12	15	52·9	68·8	27 1	43·6	52	1·42	
Series 2 Mixed minerals	Carted	Fallow	172	$13\frac{1}{8}$	53·5	74·7	28 4	39·5	72	1·21	2 C. Fa.
	Fed	Fallow	194	18	54·0	80·8	29 7	42·2	72	1·26	2 F. Fa.
	Carted	Clover	200	20	54·1	78·8	28 9	43·5	66	1·21	2 C. Cl.
	Fed	Clover	238	$29\frac{7}{8}$	55·1	84·5	29 10	44·7	59	1·37	2 F. Cl.
		Average	201	$20\frac{1}{4}$	54·2	79·7	29 1	42·5	67	1·26	
Series 3 Mixed minerals, ammonia salts and rape cake	Carted	Fallow	399	$19\frac{3}{4}$	54·4	79·2	29 10	42·7	69	1·27	3 C. Fa.
	Fed	Fallow	388	$29\frac{1}{4}$	55·1	73·8	30 6	45·2	63	1·33	3 F. Fa.
	Carted	Clover	394	28	55·1	79·2	29 9	46·0	51	1·34	3 C. Cl.
	Fed	Clover	338	$34\frac{1}{2}$	55·2	72·7	29 6	47·0	49	1·40	3 F. Cl.
		Average	380	$27\frac{7}{8}$	54·9	76·2	30 0	45·2	58	1·33	

The yield of roots on the unmanured land is practically *nil*, but on the plot where minerals (only) are applied with the roots there is, after fifty years, still generally more than half a crop of swedes; and where these are fed and there is also another still more restorative crop, as far as nitrogen supply is concerned, viz., clover in the rotation, as on Plot 2 F. Cl., the yield of barley following is in the forty-ninth year of continuous similar rotation no less than 37¾ bushels per acre, and that of over-average quality. This plot—with a rotation of (1) Roots (manured with abundant minerals, 3½ cwts. superphosphate only for the first nine rotations, and the same superphosphate with about 5 cwts. potash and other salts for the last four); (2) Barley; (3) Clover or Beans; (4) Wheat—represents what may be called low farming. No part of the white-straw crops is returned to the land, and only the underground residue (very valuable, however) of the clover is left, yet the last ten years show good average, all-round results, and even compare favourably with those given by the corresponding 3 F. Cl. plot, where the rotation is precisely the same and where 200 lbs. ammonia salts and 2,000 lbs. rape cake are added to the minerals as manure for the roots. The crops for the last ten years on these two plots are as follows:

Year		2 F. Cl. *Fed roots, barley, clover, wheat; minerals only for the roots*	3 F. Cl. *Fed roots, barley, clover, wheat; minerals, ammonia and rape cake for the roots*
1888	Turnips	12½ tons	20¾ tons
1889	Barley	29¾ bush. (26s. 6d.)	25½ bush. (26s.)
1890	Beans	24 bush.	16¾ bush.
1891	Wheat	50¼ bush.	42 bush.
1892	Turnips	12¾ tons	16¾ tons
1893	Barley	19⅝ bush. (28s.)	25½ bush. (27s. 6d.)
1894	Clover	3¼ tons	4¼ tons
1895	Wheat	39⅝ bush.	40 bush.
1896	Turnips	12 tons	16 tons
1897	Barley	37¾ bush. (31s. 6d.)	42¼ bush. (31s. 6d.)
1898	Beans	33⅛ bush.	22¼ bush.
1899	Wheat	42⅞ bush.	41⅜ bush.
	Corn	277 bush.	255⅞ bush.
	Turnips and clover	40½ tons	57¾ tons

The net result is that the addition of nitrogenous manure worth about £12 has given nearly 18 tons of additional green food (turnips and clover), but actually less corn by $21\frac{1}{2}$ bushels. The loss is mainly on the beans, which here at any rate flourish best without added nitrogenous, but with plenty of mineral, food.

Another point well worth notice is that in these last four barley years the 'fed'-roots crops have given not only, of course, better yield, but also better quality where, being fully manured, they have been a full crop. If the yield all round had been heavier, doubtless the result as to quality would have been different, as it frequently was in previous years; and if all the available indications brought forward are considered, we believe this general principle will be found to hold good: that where the season is such as to favour early rather than late vegetation, then full supply of nitrogen, such as residues from manures applied to previous roots, and also from return of same to the land, will, whilst increasing yield, not at all necessarily be prejudicial to good quality, which under these conditions may be expected with a moderately hot summer and favourable harvesting conditions. These, in fact, seem to be the conditions for good grain formation, and those which will give barley of at once good size and good maturation. The first crop of all, 1849, and that of 1857, approach nearest to fulfilling the conditions.

The best sample of the 156 (3 F. Fa. of the year 1885) was grown under the abnormal and unprofitable condition of fallowing the land one year in four, with a yield of $32\frac{1}{4}$ bushels. Where clover was sown with the barley that year, and either clover or beans had been grown following barley in every previous rotation (on the adjoining plot, 3 F. Cl.), with 12 bushels more grain, the sample was inferior by a good 3s. a quarter. It is no matter for wonder that really choice samples of barley are few and far between when such a diverse set of conditions is needful for their profitable production.

There is no question that a too-prolonged period of grain formation and maturation gives heavy, large-grained, but coarse barley, with a high nitrogen content and low malting quality. The lighter soils and special seasons which favour early but not too quick ripening give the best grain. Barley

spring-sown is a surface feeder, but how far the roots go down, how much food they draw up from below, and for how long a period, depend on the character and conditions of the soil probably more than on the weather, except with extreme seasonal conditions. This is mainly the reason why some soils most rarely produce well-matured barley. But the natural condition of a soil is greatly modified by its treatment and the character of the cropping, and more, as all recent researches abundantly prove, by clover and similar leguminous crops than by any other ordinary means.

So it is that in the Agdell field at Rothamsted the character of the grain is influenced greatly by the leguminous crop. The grain is larger and heavier, but on this particular soil too much nitrogen is made available for good maturation of barley where clover is grown. On a lighter soil, where the nitrogen was less conserved, the comparison might not, probably would not, hold good; indeed, in some districts it is no uncommon thing to meet with good samples of 'ley barley', that is, barley grown after clover ley.

One order of rotation will suit one soil and another will answer best elsewhere, and not even such a course of rotations as this at Rothamsted will answer all the questions which can be raised with respect to the influence of rotations and manures, and of both combined, on the quality of barley. The quality of the barley was probably not a factor which was much considered when the order of rotation was originally planned. On the Rothamsted soil we have little doubt that quality would be better if barley followed wheat, but for the adoption of the much more customary Norfolk rotation there were doubtless many other considerations outweighing this particular one. Still, we shall be pardoned for thinking our investigation of some value if only it leads to some definite conclusions as to how, in the long run, the character of the barley crop on this particular soil has been affected by the cultural conditions which have been adopted, some of which represent those common to a large number of districts.

It will be desirable to summarize the results of this examination of the Rothamsted rotation barley, with a view to demonstrating the relations between size and maturation on the one hand, and conditions of growth on the other.

Effects on quality of (1) *feeding and carting roots;* (2) *leguminous crop in the rotation*

The tables hitherto referred to have all shown 'averages' of periods of four rotations. The general effect of averaging the results is to diminish the differences which are shown in individual years and plots.

Still more is this the case when we average the results of the twelve barley crops grown during the whole period of forty-eight years. Table XXVI, on the next page, shows the average effects of feeding, or cutting up and spreading, as against carting roots before the barley, and also the results due to leguminous crop over the whole period. On the plots of Series 1 there are practically no root crops, and in the first part of the table the averages given are those of all the four plots of this series taken as one. To show the comparative results of feeding and carting roots on the plots of Series 2 and 3 the clovered and fallowed plots are treated as one, and similarly in the lower part of the table, to show the effects of the leguminous crop, the 'fed' and 'carted' roots plots are treated as one plot.

The figures illustrate what has been said as to the influence on the quality of the barley of cultural conditions varying in these two respects. The higher 'condition' of soil due to feeding (or spreading) the roots and to the inclusion of clover in the rotation gives larger and heavier, but generally, though not always, less well matured and more nitrogenous grain. As to market value, the differences when averaged are very slight, for what is lost in size of grain from lower soil condition is (where there has been abundant supply of phosphates) made up for by better maturation. Perhaps, judging from the determinations of mealy corns and nitrogen content, the samples from the 'carted-roots' and 'fallow' plots are better as malting material than they look. The general impression given by this table is that the average differences in value due to the different treatment are very slight, compared with the differences in yield which are in the reverse direction. This is so, but the divergences in character, so far as they are shown, are very consistent, and it is to be remembered that in most of the earlier and some of the later years these differences were

TABLE XXVI.—Agdell Field, Rothamsted, Rotation Plots

Average of twelve barley crops

Years	Manures applied to roots	Roots fed or carted	Fallow or clover after barley	Bush. per acre	Weight per bushel	Total grain to 100 total straw	Average value	Weight of 1,000 corns	Mealy corns per 100	Total nitrogen per cent. of grain	Plot
Barley averages of twelve years after carted and after fed roots											
					lbs.		s. d.	grammes			
Average of all years	None	Carted and fed	Both plots	25	53·3	85·5	27 3	44·9	57	1·40	1 C. Fa. & 1 C. Cl. 1 F. Fa. & 1 F. Cl.
Average of all years	Minerals only	Carted	Both plots	23½	54·0	92·4	28 8	43·6	70	1·24	2 C. Fa. & 2 C. Cl.
		Fed	Both plots	32⅛	54·3	92·3	29 1	44·8	64	1·31	2 F. Fa. & 2 F. Cl.
Average of all years	Minerals, ammonia salts and rape cake	Carted	Both plots	35½	54·7	91·8	29 0	45·6	65	1·34	3 C. Fa. & 3 C. Cl.
		Fed	Both plots	42¾	54·7	81·9	28 8	46·1	56	1·44	3 F. Fa. & 3 F. Cl.
Barley averages of twelve years on plots with fallow and with clover following barley											
Average of all years	None	Both plots	Fallow	25½	53·6	88·2	27 7	44·3	65	1·34	1 F. Fa. & 1 C. Fa.
		Both plots	Clover	24½	53·0	82·8	27 0	45·5	50	1·46	1 F. Cl. & 1 C. Cl.
Average of all years	Minerals only	Both plots	Fallow	25⅝	53·9	92·1	28 11	43·3	73	1·24	2 F. Fa. & 2 C. Fa.
		Both plots	Clover	30	54·3	92·6	28 9	45·1	65	1·31	2 F. Cl. & 2 C. Cl.
Average of all years	Minerals, ammonia salts and rape cake	Both plots	Fallow	37¾	54·5	87·0	29 0	45·4	66	1·36	3 F. Fa. & 3 C. Fa.
		Both plots	Clover	40½	54·9	86·9	28 8	46·4	57	1·41	3 F. Cl. & 3 C. Cl.

almost *nil*, so greatly did the seasonal influences outweigh all others.

That these differences are sometimes considerable is shown by Table XXVII, which gives an impression of the variations occurring in some seasons between grain grown under different cultural conditions, and the still greater difference which seasons make where the cultural conditions are the same. In many years, as we have already said, differences of quality due to preparation were almost *nil*; but in seasons like 1877, a more or less trying season for grain crops, there were wide differences in the character of the grain, as the figures for two plots in that year show clearly. In 1893, a disastrous season, the quality of the grain was a great contrast to that of 1877, as will be seen by comparing the results on the same plot. That year there was a hot spring which burnt up everything, followed by over five inches of rain in July, but fair weather for harvesting the very light crops, which were altogether under-matured. In 1889, to take a third year, there was a fine growing spring with plenty of vegetation, but a wet July, followed by a constantly showery harvest month and grain very much weathered.

But if the reader will refer to yet another set of figures, the conformities observable between (1) the ratio of grain to straw, (2) the size of the grain, (3) the degree of maturation and (4) the percentage of total nitrogen are, we think, sufficiently instructive to be pointed out in some detail, and to facilitate this there is shown in Table XXVIII, p. 223, the relative order of the plots in these respects.

Considering the difficulty of ensuring absolutely average samples for the different determinations, and making some allowance for errors of experiment, there is close conformity in all three periods between the mellowness of the grain and the percentage nitrogen content, the mellow grain containing the lowest proportion of nitrogenous matter. Grain which is good in these respects is generally, but with much less close conformity, produced where the ratio of grain to straw is high, and, where straw is disproportionately heavy, grain is nearly always worse matured.

In the first period there is little difference in the size of the grain on the different plots, and size bears no definite relation to maturation; but the best three plots in respect of ratio of

TABLE XXVII.—Agdell Field, Rothamsted, Rotation Plots

Barley of the same year on different plots, and of different years on the same plot

Years	Manures applied to roots	Roots fed or carted	Fallow or clover after barley	Bush. per acre	Weight per bushel	Total grain to 100 total straw	Value		Weight of 1,000 corns	Mealy corns per 100	Total nitrogen per cent. of grain	Plot
					lbs.		s.	d.	grammes			
1877	Minerals only	Carted	Fallow	21	54·5	118·6	31	6	45·1	88	1·20	2 C. Fa.
1877	Minerals, ammonia salts and rape cake	Fed	Clover	49⅛	55·7	90·8	30	0	47·6	50	1·52	3 F. Cl.
1893	Minerals, ammonia salts and rape cake	Fed	Clover	25½	57·1	75·9	27	6	51·8	26	1·74	3 F. Cl.
1889	Minerals, ammonia salts and rape cake	Fed	Clover	25½	53·4	67·9	26	0	45·0	83	1·27	3 F. Cl.
1889	Minerals only	Carted	Fallow	15⅛	52·6	83·9	26	0	41·3	86	1·08	2 C. Fa.

Table XXVIII.—Agdell Field, Rothamstead, Rotation Plots. Relation between (1) ratio of grain to straw, (2) degree of maturation, (3) nitrogen content, (4) size of grain grown on twelve plots in three periods.

Averages of 1853, 1857, 1861, 1865

—	Total grain to 100 total straw from highest to lowest		Maturation: mealy corns per 100 from highest to lowest		Nitrogen per cent. of grain from lowest to highest		Size: weight of 1,000 corns from lowest to highest	
1	2 C. Fa.	102·5 to 97·4	2 C. Cl.	71 to 69	2 F. Fa.	1·32 to 1·34	2 C. Fa.	45·6 to 47·6
2	2 C. Cl.		2 C. Fa.		2 C. Fa.		1 F. Cl.	
3	2 F. Fa.		2 F. Fa.		2 C. Cl.		2 F. Fa.	
4	3 C. Fa.	97·1 to 92·5	3 C. Fa.	65 to 60	1 F. Fa.	1·39 to 1·47	2 C. Cl.	
5	1 F. Fa.		2 F. Cl.		3 C. Fa.		3 F. Fa.	
6	3 C. Cl.		1 F. Fa.		1 C. Fa.		1 C. Fa.	
7	1 C. Fa.		1 C. Cl.		2 F. Cl.		1 C. Cl.	
8	2 F. Cl.		1 C. Fa.		1 C. Cl.		3 F. Cl.	
9	1 C. Cl.		3 C. Cl.		3 C. Cl.		1 F. Fa.	
10	1 F. Cl.	92·0 to 82·7	3 F. Fa.	58 to 49	1 F. Cl.	1·48 to 1·61	2 F. Cl.	
11	3 F. Cl.		1 F. Cl.		3 F. Fa.		3 C. Fa.	
12	3 F. Fa.		3 F. Cl.		3 F. Cl.		3 C. Cl.	

Averages of 1869, 1873, 1877, 1881

1	3 C. Fa.	101·0 to 94·7	2 C. Fa.	78 to 76	2 C. Fa.	1·13 to 1·19	2 C. Fa.	42·7 to 45·0
2	2 C. Fa.		2 F. Fa.		2 F. Fa.		1 C. Fa.	
3	2 F. Cl.		3 C. Fa.	70 to 64	1 F. Fa.	1·22 to 1·30	2 F. Fa.	
4	3 C. Cl.		3 C. Cl.		2 C. Cl.		1 F. Fa.	
5	2 C. Cl.		1 F. Fa.		3 C. Fa.		2 C. Cl.	
6	2 F. Fa.		1 C. Fa.		1 C. Fa.		3 C. Fa.	
7	1 F. Fa.		2 C. Cl.		2 F. Cl.		2 F. Cl.	
8	1 C. Fa.		2 F. Cl.		3 C. Cl.		1 F. Cl.	45·5 to 45·6
9	1 C. Cl.	93·7 to 90·8	3 F. Fa.	64 to 53	1 F. Cl.	1·32 to 1·34	1 C. Cl.	
10	1 F. Cl.		3 F. Cl.		1 C. Cl.		3 C. Cl.	
11	3 F. Cl.	89·3 to 88·4	1 F. Cl.		3 F. Fa.	1·34 to 1·41	3 F. Fa.	46·2
12	3 F. Fa.		1 C. Cl.		3 F. Cl.		3 F. Cl.	

Averages of 1885, 1889, 1893, 1897

1	2 F. Cl.	84·5 to 72·2	2 C. Fa.	72 to 66	1 F. Fa.	1·19 to 1·27	2 C. Fa.	39·5 to 43·5
2	2 F. Fa.		2 F. Fa.		2 C. Fa.		2 F. Fa.	
3	3 C. Cl.		3 C. Fa.		2 C. Cl.		1 C. Fa.	
4	3 C. Fa.		1 F. Fa.		2 F. Fa.		3 C. Fa.	
5	2 C. Cl.		2 C. Cl.		3 C. Fa.		1 F. Fa.	
6	1 F. Fa.		3 F. Fa.	63 to 49	1 C. Fa.	1·30 to 1·40	2 C. Cl.	
7	2 C. Fa.		1 C. Fa.		3 F. Fa.		1 F. Cl.	44·3 to 44·7
8	3 F. Fa.		2 F. Cl.		3 C. Cl.		1 C. Cl.	
9	3 F. Cl.		3 C. Cl.		2 F. Cl.		2 F. Cl.	
10	1 C. Fa.		3 F. Cl.		3 F. Cl.		3 F. Fa.	
11	1 F. Cl.	68·2 to 60·0	1 F. Cl.	45 to 33	1 F. Cl.	1·54 to 1·65	3 C. Cl.	
12	1 C. Cl.		1 C. Cl.		1 C. Cl.		3 F. Cl.	

grain to straw are the same three which have the best-matured grain with lowest nitrogen content, and the worst three plots are those in which these conditions are all reversed. In the two later periods the effects of extreme exhaustion on the plots of Series 1 upset the conformity in some respects, but it is still very marked as between good maturation and low nitrogen content and vice versa. In these two periods the smaller grain is the best-matured generally. This relation between size of grain and maturation is a most important one in the case of malting barley, especially in connection with the introduction of new varieties, and it undoubtedly requires further investigation, with a view to the demonstration, if possible, of conditions under which good size and good maturation will go together.

Referring to Table XXIX, p. 225, if we leave out the unmanured plots where extreme exhaustion has led to results which are not conformable with those of the other plots, we shall see that, taking the grain of the whole period, the relations between grain formation, size, maturation and percentage of nitrogenous matter are very clear, and confirm unmistakably the conclusions which we have already reached. With all these different conditions of preparation for the barley, good grain formation (ratio of grain to straw) goes along with comparatively small but kindly, well-matured corn, of high carbohydrate but low nitrogenous composition. The best quality, apart from size, is found where there has been no restorative crop for over fifty years, where everything grown has been removed, and where nothing but mineral manure has been applied; needless to add the yield has been very small. The largest grain, but the worst in other respects, is that of the plot where two crops out of four have been restorative, where plentiful and complete manuring has given heavy root crops, fed off (or cut up and spread), and followed by high yields of barley.

The Rothamsted results with barley grown in the Norfolk rotation extending over more than fifty years and with twelve different cultural conditions lead to the following conclusions:

(*a*) The good effect of soluble phosphates on quality of grain is (as was also shown with continuously grown barley) most marked. The plots manured with minerals only have

TABLE XXIX.—Agdell Field, Rothamsted, Rotation Plots. Relation between average (1) ratio of grain to straw, (2) size of grain, (3) maturation, (4) percentage of nitrogen, in the crops of the manured plots for the twelve barley years between 1853 and 1897.

Manures applied to roots	Roots fed or carted	Fallow or clover after barley	Total grain to 100 total straw	Size of grain: weight per 1,000 corns	Maturation: mealy corns per 100	Nitrogen per cent. of grain
				grammes		
Minerals only	Carted	Fallow	92·6	42·6	73	1·22
	Fed	Fallow	91·7	44·1	72	1·26
	Carted	Clover	92·3	44·6	68	1·26
	Fed	Clover	93·0	45·6	62	1·36
Minerals, ammonia salts, and rape cake	Carted	Fallow	92·4	44·9	68	1·31
	Fed	Fallow	81·6	45·9	62	1·41
	Carted	Clover	91·3	46·4	60	1·37
	Fed	Clover	82·2	46·6	53	1·47

given the best yield of grain in proportion to straw, showing the unmistakable effect of phosphates in assisting grain formation. This series of plots also shows a lower percentage in the grain of nitrogenous matters than either of the other series. The barley, though often comparatively small, is well matured—better in this all-important respect than where no phosphates are applied, and also better than where, with heavy nitrogenous dressings in addition to minerals for the preceding roots, the land is in better condition and gives much higher yields.

(*b*) As between roots carted and roots fed as preparation for barley, the effect of the higher manuring on the quality of the succeeding barley is not very great either way at Rothamsted, taking the average of the years, although of course there is much heavier yield after roots fed than where the roots have been carted. The maturation of the grain is frequently, though by no means always, better after carted roots, but the difference in this respect is counterbalanced by an almost uniformly larger grain on the 'fed' plots, counterbalanced that is, as far as what, to the best of our judgement, would be the relative market value of the grain; but we think, in view of our determinations of degree of maturation and

content of nitrogenous matters, that the 'after-roots-carted' barleys are better than they look in relation to those after roots fed (or cut up and spread). In any case it has to be remembered that no added food of any sort has ever been fed on the plots, and that therefore the generally accepted opinion that roots fed, with oil-cake added, is too good a preparation for barley, as far as quality is concerned, is not controverted by these results.

(*c*) The general effect of high 'condition' of soil on the quality of barley is shown at Rothamsted in the comparison afforded between clover as against a year's fallow in the rotation. The average results under every condition of preparation for the root-crop show that this leguminous crop leaves a residue which increases the yield, but gives less well-matured grain. Apart, however, from the value of the included clover crop, the increased yield of grain more than compensates for the somewhat lower maturation. It is a remarkable fact that the effect of this crop is, in the more recent years, more apparent upon the barley three years after than it is upon either the wheat or roots which intervene. It points to the fact that barley is, of all the farm crops, the one which is most affected by 'condition' of soil, and this is true not only of the total amount of produce, but also of the character of the grain.

These relations of cultural conditions to quality are fully illustrated by Tables XXVI to XXIX.

The fact that too high condition of soil is not conducive to good quality in barley points to 'after wheat' as the best preparation for the barley crop. This plan is not of course adopted solely, or even mainly, in view of better probable quality of barley. It suits the arrangements of the farm in many other respects in some districts. As regards the barley, what is lost from lower 'condition' of soil as against 'after-roots-fed' is frequently made up for, in respect of yield, by the better tillage possible, and in quality by the better maturation which is due to earlier seeding and ripening. Early seeding is not always possible after roots, and the more 'kindly' if smaller grain which is generally produced in districts where the 'after-wheat' practice is the custom is, we think, the combined result of generally more favourable conditions for the ultimate maturation of the grain.

On examining the samples of the rotation plots we found that the differences due to season were far greater than those due to variations in the rotation, and the divergences in quality in the rotation plots are less than with the continuous barley plots.

Relation of Migration (ratio of grain to straw) to Nitrogen Percentage of Grain of Agdell Field samples

Taking the figures relating to the above factors as a 'population' of 144, representing samples grown in all sorts of soil and weather conditions resulting in a range of crops from 11 to 66 bushels per acre—with nitrogen ranging from 1·11 to 1·94 per cent., and migration from 35 to 53 per cent. —$r_{mn} = -\cdot 31$.

Taking 12 'populations'—one for each barley year—representing for each year samples grown under 12 different *soil conditions,* we get:

	r_{mn}		r_{mn}
1853	$-\cdot 88$	1877	$-\cdot 81$
1857	$-\cdot 69$	1881	$-\cdot 48$
1861	$-\cdot 78$	1885	$-\cdot 59$
1865	$-\cdot 91$	1889	$-\cdot 62$
1869	$-\cdot 29$	1893	$-\cdot 13$
1873	$-\cdot 32$	1897	$-\cdot 82$

12 years' average $= -\cdot 61$.

Excluding the years 1869, 1873 and 1893:

9 years' average $= -\cdot 73$

Taking the figures as a single 'population' of 12 years—representing 12 averaged samples of 12 plots each grown under 12 different weather conditions, r_{mn} is then $-\cdot 148$.

It appears evident that with the conditions of this field, i.e. widely varying soil but similar weather, nitrogen content is influenced by differences in migration due to manuring or soil conditions, or both, due to the same cause; but it is much more marked in some years than in others. This appears to confirm the statement already made that in the later stages of maturation of the grain there is generally a greater proportion of the carbohydrate than of proteid matter 'migrated' than in the early stages.

N.B.—The 'migration' figures are subject to a large probable error because they are based on an assumed water

content of 17 per cent. each year for both grain and straw at time of threshing and weighing the crops. They would also be affected by varying length of the stubble left uncut.

These errors of observation are unlikely to be correlated with either migration or nitrogen, and would therefore probably tend to lower the calculated *r*, and the true *r* is probably a higher minus quantity than the calculated one represents.

CHAPTER XXII

EXPERIMENTS WITH OLD ESTABLISHED VARIETIES AND RACES

In 1900 an extended set of trial plots was started at Warminster. The barleys selected for trial under strictly parallel conditions were: (1) Three wide-eared sorts, Invincible, Standwell and Goldthorpe; (2) Four narrow-eared sorts: (*a*) Hanna, a very early ripening, short-strawed Moravian barley; (*b*) two well-known sorts of true Chevalier, Nos. 1 and 2; and, lastly, (*c*) the somewhat later ripening, also well-known sort, Archer stiff-straw.[1]

No. 1 Chevalier was selected for its size, and No. 2 for fine quality.

In 1900 these seven sorts were grown under three different conditions as to quantity of seed, viz., 3 bushels per acre in drills 7 in. apart; 1½ bushels in drills 14 in. apart; and 1 bushel in drills 21 in. apart. The weight of seed in each drill was therefore the same in all cases. The excessive widths between drills (14 in. and 21 in.) and the small weight of seed on unit area were adopted with the special object of exaggerating the effects due to thin seeding.

The plots were all further subdivided for manurial purposes into four divisions, receiving respectively liberal dressings of (1) guano, (2) phosphates, (3) phosphates and nitrate, (4) phosphates, nitrate and potash.

In 1901 the plots were severally seeded from the grain grown thereon the previous year, with a view to eliminating effects due to origin of seed from different localities. The seeding was 4, 2 and 1½ bushels per acre in drills respectively 4, 8 and 12 in. apart; and the manures the same, and on the same areas as in the previous year. Eighty-four different samples had therefore been obtained in each year.

[1] I have never been able to ascertain definitely the origin of this sort, but it is well adapted for winter-sowing. It has been greatly improved upon in recent years. A small bristly brush at the germ end of the grain can be found on examination and this is persistently inherited.

Some of the results of the above experiments are shown in Tables XXX to XXXVI.

Tables XXX and XXXI illustrate for each variety the effects of extreme variations in methods of cultivating in two seasons. They show that effects due to cultivation are much greater than those associated with particular varieties.

Tables XXXII and XXXIII afford a comparison between the four typical varieties each grown under four conditions as to manure. They show that the differences in quality due to manuring in these years were comparatively slight.

The yield with phosphates only is generally about one-third less than where nitrogen, either as nitrate or as guano, is added. The effect of potash in 1900 was not to improve the quality, but in 1901 the barleys with potash were distinctly the best.

Tables XXXIV, XXXV and XXXVI show the effects of close and wide planting in the case of each of the four typical varieties. The plots with the greater soil space per plant produced grain of higher nitrogen content and of low malting quality.

As between the different manurial treatments in 1900 the 'phosphate only' barleys (with very low yield) were the best judged by appearance, while of the varieties the Chevaliers and Hannas were the kindliest barleys, though much smaller than the Goldthorpes.

In 1901 the best sample in appearance was the Chevalier, with full mineral manuring, including potash. The Goldthorpes are again the largest grain.

Taking the average of all the samples and valuing them by their appearance as malting material, the barleys grown with a view to quality (that is, without nitrogenous manuring and closely planted), taken on the whole, would be placed in the following order of merit: 1. Hanna; 2. Chevalier; 3. Goldthorpe; 4. Archer.

With nitrogenous manures and planted rather for yield, the order would be: 1. Goldthorpe; 2. Hanna; 3. Chevalier; 4. Archer.

The Archers were not so satisfactory as the others either in respect of quality or of yield, but probably with earlier planting and in more forward seasons than those of

1900 or 1901 they would have taken a higher place.[1] Probably also the Archers were cut a day or two too soon, but the weather was changeable at harvest-time in both seasons and there was more risk in leaving them than in cutting them.

TABLE XXX.—Warminster Plots, 1900. Effects of different Seed Rates and Manurial Treatments on different Varieties

Variety	Seed, lbs. per acre	Inches between ranks	Manure m = mineral g = guano	Wt. per 1,000 corns	Mealy corns per 100	Total N. per cent. barley
				grammes		
Invincible	168	7	m	48·8	46	1·28
Invincible	56	21	g	51·1	42	1·68
Standwell	168	7	m	46·4	46	1·25
Standwell	56	21	g	53·5	36	1·59
Goldthorpe	168	7	m	46·1	52	1·25
Goldthorpe	56	21	g	53·4	38	1·74
Hanna	168	7	m	40·1	46	1·39
Hanna	56	21	g	48·1	..	..
Chevalier	168	7	m	41·6	36	1·32
Chevalier	56	21	g	51·2	34	1·88
Chevalier	168	7	m	46·9	48	1·09
Chevalier	56	21	g	53·7	38	1·75
Archer	168	7	m	45·0	46	1·18
Archer	56	21	g	51·5	34	1·65

TABLE XXXI.—Warminster Plots, 1901. Effects of different Seed Rates and Manurial Treatments on different Varieties

Variety	Seed, lbs. per acre	Inches between ranks	Manure m = mineral g = guano	Wt. per 1,000 corns	Mealy corns per 100	Total N. per cent. barley
				grammes		
Invincible	224	4	m	53·2	54	1·34
Invincible	75	12	g	57·6	58	1·72
Standwell	224	4	m	50·6	46	1·39
Standwell	75	12	g	58·9	52	1·66
Goldthorpe	224	4	m	51·3	62	1·43
Goldthorpe	75	12	g	58·7	46	1·87
Hanna	224	4	m	47·1	62	1·34
Hanna	75	12	g	52·1	38	1·78
Chevalier 1	224	4	m	48·9	58	1·36
Chevalier 1	75	12	g	55·9	48	1·76
Chevalier 2	224	4	m	48·1	64	1·36
Chevalier 2	75	12	g	53·4	28	1·79
Archer	224	4	m	48·2	60	1·34
Archer	75	12	g	53·4	38	1·90

[1] In both the series of experiments described all the sorts were sown together in the middle of March, and this was disadvantageous to the Archer barley, which does best with earlier sowing.

TABLE XXXII.—Warminster Plots, 1900. Effect of Various Manures on Different Varieties. 168 lbs. Seed per Acre

Variety	Manure	Wt. per 1,000 corns	Mealy corns per 100	Total N. per cent. barley
		grammes		
Goldthorpe .	Phosphates	50·1	70	1·15
Goldthorpe .	Phosphates + nitrate	50·1	54	1·16
Goldthorpe .	Phosphates + nitrate + potash	46·1	52	1·25
Goldthorpe .	Guano	51·9	48	1·26
Average .	..	49·5	56	1·20
Hanna . .	Phosphates	45·4	52	1·12
Hanna . .	Phosphates + nitrate	44·8	48	1·16
Hanna . .	Phosphates + nitrate + potash	40·1	46	1·39
Hanna . .	Guano	45·6	34	1·23
Average .	..	43·9	45	1·22
Chevalier 1 .	Phosphates	42·9	44	1·26
Chevalier 1 .	Phosphates + nitrate	44·1	48	1·09
Chevalier 1 .	Phosphates + nitrate + potash	41·6	36	1·32
Chevalier 1 .	Guano	45·4	38	1·33
Average .	..	43·5	41	1·25
Archer . .	Phosphates	45·0	46	1·27
Archer . .	Phosphates + nitrate	46·8	56	1·15
Archer . .	Phosphates + nitrate + potash	45·0	46	1·18
Archer . .	Guano	48·1	38	1·36
Average .	..	46·2	46	1·24

The fact which comes out with most prominence from a study of the results of these trials is that if we cannot make sure under any specified conditions of soil and climate, or with any one race of barley, of getting what we want, it is easier to make reasonably sure of doing the reverse, and the knowledge 'how not to do it" may be of some service. The barley which is not wanted for brewing is the coarse, hard, nitrogenous, two-rowed grain; such barley will not compete with foreign six-rowed sorts.

To grow a coarse plant which will only mature large steely unworkable grain it is only necessary to give the individual seed at and after planting time over-abundant soil space and over-abundant plant food. This fact will be accepted by every observant grower.

Table XXXIII.—Warminster Plots, 1901. Effect of Various Manures on Different Varieties. 224 lbs. Seed per Acre

Variety	Manure	Wt. per 1,000 corns	Mealy corns per 100	Nitrogen per cent. barley
		grammes		
Goldthorpe .	Phosphates	48·9	64	1·58
Goldthorpe .	Phosphates + nitrate	50·5	64	1·53
Goldthorpe .	Phosphates + nitrate + potash	51·3	62	1·43
Goldthorpe .	Guano	52·3	52	1·46
Average .	..	50·7	60	1·50
Hanna . .	Phosphates	47·5	58	1·55
Hanna . .	Phosphates + nitrate	48·4	44	1·53
Hanna . .	Phosphates + nitrate + potash	47·1	62	1·34
Hanna . .	Guano	50·2	58	1·48
Average .	..	48·3	55	1·47
Chevalier 1 .	Phosphates	49·0	60	1·54
Cheavlier 1 .	Phosphates + nitrate	48·9	60	1·37
Chevalier 1 .	Phosphates + nitrate + potash	48·9	58	1·36
Chevalier 1 .	Guano	48·8	50	1·78
Average .	..	48·6	57	1·51
Archer . .	Phosphates	46·6	56	1·53
Archer . .	Phosphates + nitrate	49·1	46	1·54
Archer . .	Phosphates + nitrate + potash	48·2	60	1·34
Archer . .	Guano	48·2	40	1·69
Average .	..	48·0	50	1·52

The less competition and the less restriction there is in root development in the early stages, the more gross will be the vegetation and the greater the risk of coarse grain. Take an extreme case—if on, say, 24 square inches of surface there be one plant only, bearing (as it readily will) 10 stems, there will be, at the start and for some time after, no root competition of adjacent plants: the roots will be strong, spreading, and deep in the soil. There will be 10 large stout stems of different ages, ripening at different times, and producing an uneven and altogether undesirable sample. On the other hand, let there be 10 individual plants on an adjacent equal area of the same soil, and there will be perhaps 20 stems—one only to some plants, two or three to others—and the average size and weight of each stem and of each ear will be about half as great as in the former case. Root competition

TABLE XXXIV.—Warminster Plots, 1900. Close and Wide Planting

Variety	Seed, lbs. per acre	Inches between ranks	Wt. per 1,000 corns	Mealy corns per 100	Total N. per cent. barley
			grammes		
Goldthorpe .	168	7	50·0	52	1·25
Goldthorpe .	84	14	49·8	48	1·30
Goldthorpe .	56	21	52·1	44	1·46
Average .	..	..	50·6	48	1·34
Hanna . .	168	7	43·0	50	1·24
Hanna . .	84	14	45·9	40	1·37
Hanna . .	56	21	..	34	1·57
Average .	..	..	..	41	1·39
Chevalier . .	168	7	42·8	46	1·23
Chevalier . .	84	14	47·3	36	1·51
Chevalier . .	56	21	49·3	36	1·62
Average .	..	..	45·8	39	1·46
Archer . .	168	7	46·0	44	1·25
Archer . .	84	14	49·9	38	1·39
Archer . .	56	21	47·3	38	1·48
Average .	..	..	47·7	40	1·37

will commence early and the stems will be shorter. The total weight of straw and grain may in the two cases be about the same, but the character of the grain will be different.

These experiments were preliminary, and should be interpreted with the strict limitation that they are results on one kind of soil and of two seasons only. They present many points of resemblance, but it is not at all probable that they would be the same in every season.

The effects on quality of the grain of different manures were generally confirmatory of those obtained from the previous examination of the Rothamsted samples, and the conclusion arrived at was that certain varieties were more affected than others by full supply of nitrogen in the soil.

The effect of nitrogenous manuring on the narrow-eared barleys was (as with Rothamsted samples which were also narrow-eared sorts) to increase the nitrogen content of the grain. This increase was considerably less with the wide-

TABLE XXXV.—Warminster Plots, 1901. With Nitrogenous Manure. Close and Wide Planting

Variety	Seed, lbs. per acre	Inches between ranks	Wt. per 1,000 corns	Mealy corns per 100	Total N. per cent. barley
			grammes		
Goldthorpe .	224	4	51·0	52	1·41
Goldthorpe .	112	8	56·3	60	1·51
Goldthorpe .	75	12	57·8	54	1·78
Average .	..	..	55·0	55	1·57
Hanna . .	224	4	48·4	60	1·41
Hanna . .	112	8	50·2	46	1·58
Hanna . .	75	12	52·4	44	1·67
Average .	..	..	50·3	50	1·55
Chevalier 1 .	224	4	48·2	56	1·46
Chevalier 1 .	112	8	53·0	40	1·81
Chevalier 1 .	75	12	53·9	38	1·86
Average .	..	..	51·7	45	1·71
Archer . .	224	4	48·1	46	1·41
Archer . .	112	8	48·8	36	1·96
Archer . .	75	12	53·0	31	2·04
Average .	..	..	49·9	38	1·80

eared sorts, and this confirmed a prevalent opinion that the wide-eared barleys are better suited for growing on the heavier and more fertile soils.

In the case of each of the varieties, the plots with the greater average soil space per plant produced grain of higher nitrogen content and lower malting quality. Here again the difference was generally less with the wide-eared sorts than with the narrow-eared.

Various other observations were made referring to different criteria of quality, notes on which are not inserted in the tables here given.[1]

It was observed that all the plots showed considerable dissimilarity as between individual plants in the same plot. This was, in some cases, no doubt due to the fact that the parcels of seed were ordinary farmers' stocks with no

[1] The original memoir on these experiments is still in existence and could be referred to by anyone who is interested in the subject.

guarantee of 'purity of sort', and there had probably been some accidental mixture in the crops from which the seed

TABLE XXXVI.—Warminster Plots, 1901. Without Nitrogenous Manure. Close and Wide Planting

Variety	Seed, lbs. per acre	Inches between ranks	Wt. per 1,000 corns	Mealy corns per 100	Total N. per cent. barley
			grammes		
Goldthorpe .	224	4	48·9	64	1·58
Goldthorpe .	112	8	55·9	60	1·46
Goldthorpe .	75	12	58·3	52	1·72
Average .	..	..	54·4	58·6	1·59
Hanna . .	224	4	47·5	58	1·55
Hanna . .	112	8	49·1	48	1·53
Hanna . .	75	12	51·4	46	1·65
Average .	..	..	49·3	51	1·58
Chevalier 1 .	224	4	49·0	60	1·54
Chevalier 1 .	112	8	52·9	52	1·62
Chevalier 1 .	75	12	55·5	34	1·69
Average .	..	..	52·5	49	1·62
Archer . .	224	4	46·6	56	1·53
Archer . .	112	8	47·7	44	1·47
Archer . .	75	12	53·3	40	1·81
Average .	..	..	49·2	47	1·60

was taken. The diversity was more marked in the 'Archer' plots and it was the observation of this diversity which first suggested to me the desirability of selecting individual plants and raising 'pure races' from them.

CHAPTER XXIII

SELECTION FROM AMONGST OLD ESTABLISHED VARIETIES

WHEN uniformity and evenness of sample in the resulting crops are desired a new race is best originated by the selection of single plant cultures from an old variety known to be composed of individuals which, although more or less alike in appearance, differ in various inheritable characters.

The process adopted is to grow on for several years the produce of the seeds of a number of single plants, keeping the various cultures distinct until they can be compared both for yield and quality. Then the best cultures are selected and further multiplied. Our best-known old varieties, Chevalier and Goldthorpe, no doubt originated in this way. English Archer and Beaven's Plumage originated similarly in the Warminster nursery and went into general cultivation in 1904 and 1905 respectively. Danish Archer and Irish Archer were both selected by similar methods, as described by Dr. Hunter (1926).

Some of the races of barley that were in existence about forty years ago, although called 'varieties' were not 'pure lines' in this sense, but mixed races. That is to say, if individual plants were picked out and the seeds kept separate from year to year and then grown up in bulk there would be differing quality and also differing constitution and habit of plant in the several cultures made.

I had this experience when selecting Archer barley. I found that as it was commonly grown it was more or less a mixture of races and therefore not uniform in quality, though it had certain general characteristics and had always been a high-yielding variety.

Generally speaking, selection from single plant cultures, having self-fertilized ancestors, gives races with a wider range of adaptation in respect of high productivity than does the produce of hybrids, but to obtain specific qualities in the plants and in the grain hybridization is necessary.

It may be considered an open question whether two races of barley (each the progeny of single plants), both selected from the same apparently 'pure line', as judged from the appearance and known ancestry of the two parents, will remain constantly alike in all their inherited characters.

Whatever theory may be accepted as to the origin of genetic variations, it seems improbable that any two races of parent plants will be precisely alike genetically, or, to use Mendelian phraseology, will be 'homozygous' in respect of all characters. If the number of variable characters in barley may be counted by hundreds (as is probable), or by thousands (as is possible), the chances are against the absolute 'homozygosity' of any two individual plants existing on the face of the globe, even if they are proved (which could seldom be the case) to have a common descent through many generations of self-fertilized plants. The fluctuating variations which are always present will preclude any certainty as to complete homozygosity in any two individuals.

'Pure Race' (or 'Single Line') Cultures raised at Warminster

These cultures have been conducted on nursery and field plots at Warminster since 1902. In that year 296 cultivations were made of twelve plants, each from 296 ears of different plants, all of known and different origin collected from various parts of this and other countries.

The progeny of many of these has been continued as distinct cultures and in each succeeding year the number has been added to, so that a very large number of distinct 'pure races' started from single plants have been under observation.

Two of these races proved of sufficient merit in comparison with the then existing varieties and races to go into general cultivation, viz., Plumage and English Archer.

The progeny of selected plants of these two races was, in each case, in successive years, submitted to methods of comparison which originated in the Warminster nursery and were afterwards adopted by the University Farm, Cambridge, by the Irish Department of Agriculture, and many years later, in 1921, by the National Institute of Agricultural Botany, Cambridge.

Beaven's Plumage (343)

History.—'Plumage' belongs to a general type of wide-eared barley, closely resembling 'Goldthorpe' and known in Sweden as 'plumage korn'.

I received from Mr. Karl Hansen, of Lyngby, Denmark, a collection of 300 ears of barley, all different and botanically named. 'Beaven's Plumage' was the progeny of a single plant grown from No. 343 of this collection.

From 1902 to 1904 this culture proved to be of better quality than any other wide-eared barley in my possession with which it was compared each year in the nursery. It was multiplied by cultivation in field plots near Warminster, and on the plots of the University Farm, Cambridge, in 1906 and 1907. A small stock of it went into cultivation in Scotland, Yorks, Essex, and some districts of the south-west in 1907. It went into general cultivation in 1909.

The progeny of this stock and of some re-selections of it are still preferred to other sorts by many Yorkshire growers.

A pure cultivation of this barley is repeated year after year in the nursery and field plots at Warminster.

Description.—'Plumage' (343) is a 'pure race' of the wide-eared variety *Hordeum zeocriton*, var. *erectum*.

The grain is slightly longer in shape and of a rather deeper yellow colour (except in hot and dry seasons) than other races of the same class. The straw is long, and the ear emerges on a long neck from the upper leaf sheath (Fig. 29). On account of the length of its neck and the heavy weight of its ear the straw is liable to 'kink', and in some cases (in unfavourable weather and situation) to break a few inches below the ear if allowed to stand until overripe.

The rachis or axis of the ear is also rather brittle when overripe and liable to break during threshing with the grains still adherent to it.[1] This brittleness of the neck and rachis, with firm adherence of the grain to the rachis, is characteristic of many of the wide-eared (*erectum*) barleys, but for some reason the defect appears to be more developed on certain

[1] Brittle rachis in barley is probably a case of reversion to an ancestral type. In the wild form of barley (*Hordeum spontaneum*, C. Koch), which is possibly the ancestor of all the cultivated sorts, the rachis (as with many of the grasses) falls to pieces on ripening with a segment of it adhering to each seed.

soils than on others and it is more prevalent in early than in late localities.

Plumage thrives best on fairly deep soils and on land in good condition, and is less suited for growing after other white-straw crops and on thin, sandy, or early soils.

The growing period of Plumage is about the same as that of Chevalier when sown at the same time, and about a week less than that of Archer barley. It is therefore more suited than Archer to late districts. Owing to its brittle rachis it is best cut before it is overripe.

As an illustration of the productivity of this race under the most favourable conditions, Sir Harry Hope, of Barneyhill, near Dunbar, grew about 600 acres on his farm between 1908 and 1913. It yielded an average of over 60 bushels per acre, which, at that time, was probably a record for barley growing on any farm in the United Kingdom.

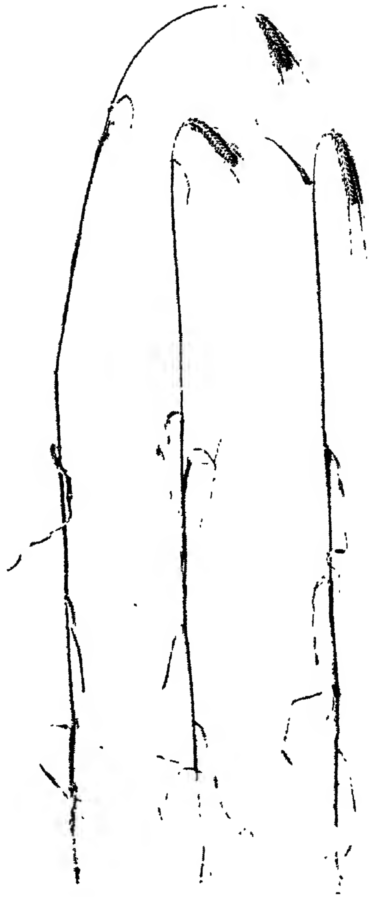
The results in each year were as follows:

1909.	81 acres.	Average yield per acre: 62 bushels
1910.	70 acres.	Average yield per acre: 56 bushels
1911.	90 acres.	Average yield per acre: 64 bushels
1912.	180 acres.	Average yield per acre: 60 bushels
1913.	190 acres.	Average yield per acre: 66 bushels

Beaven's English Archer (4)

History.—'Archer' or 'Archer stiff straw' barley of various races, generally more or less mixed in cultivation but with a general similarity of character, had been well known in the Eastern Counties for a great number of years. It is probably one of the oldest types of British barley. The same type of barley is known by the name 'Prentice' on the Continent, and several 'pure races' have originated by its selection in Denmark, Sweden and Germany. It has also been grown up from 'single plant' cultures and widely distributed in Ireland by the Department of Agriculture there.[1] [It was named

[1] The Irish experiments were started in 1901 and the Archer then used was the old unselected stock. The single plant cultures of Irish Archer (1) began in 1904. The first introduction of Archer into Ireland took place in 1899 on the suggestion of Mr. Free, of Mistley, Essex, but Scotch Chevalier, Standwell and Old Irish were the prevailing sorts at that time in the country generally.



P. P.A. A.

FIG. 29.—Plants of Plumage, Plumage-Archer and Archer.
(See page 242.)

To face page 240

'Prentice' because it resembled a barley of that name sent by Mr. Ernest Prentice, a well-known seedsman, to Denmark for experiments, but this was afterwards found to be a different variety.] Comparative trials of Archer, both of unselected and selected stocks, by various authorities in the Eastern Counties, in Denmark, and in Ireland, have shown this type (and more especially the selected races of it) to be generally much more productive than either Chevalier or wide-eared barley. It was discovered by Mr. Alan McMullen (of the staff of Messrs. Guinness, Dublin) when he visited Denmark in 1904 that 'Prentice', so called, was in fact 'Archer', and this provided strong *prima facie* evidence that Archer was a higher yielding barley than either Chevaliers or Goldthorpes. It was certainly this discovery that gave the cultivation of Archer its impetus, and since that time we have gone steadily forward improving barley on both sides of the Irish Channel and always with Archer as one parent.

Beaven's English Archer (4) is a 'pure race' of *Hordeum distichum*, var. *nutans*, which originated in a single plant culture selected for superior productivity and quality from a large number of similar single plant cultures started from ears of Archer barley collected in various parts of England and grown in the Warminster nursery in 1903. English Archer (4) was grown on field plots near Warminster in 1906 and on the plots of the University Farm at Cambridge in 1907 and following years. It was afterwards distributed in the Eastern Counties from the University Farm and from the Norfolk Agricultural Station at Little Snoring. The first farm crop in the south-west of England was grown by Mr. Cary Coles, of Winterbourne Stoke, Wilts, in 1908, from whence it spread extensively into general cultivation in Wiltshire and Dorsetshire. It was repeatedly tested on County Council plots in the Eastern Counties and by the Royal Agricultural Society at Woburn, and has given high yields compared with other sorts.

English Archer gradually ousted Chevalier as fast as maltsters discovered that, although inferior in appearance to Chevalier, it provided them with better malting material.

Description.—The straw is of the characteristic Archer type, comparatively short, and the ear emerges only a few inches from the leaf sheath (Fig. 29). There is therefore only a

short neck, which is free from any tendency to kink. The ear is rather less narrow than that of Chevalier barleys. The grain is distinguishable from Chevalier by the bristly rachilla, i.e. the small rudimentary structure which lies in the furrow of the grain. The colour of the grain is a greyish-yellow, but brighter and more uniform than the old unselected Archer.

This barley does not shoot up quite as quickly as some of the other sorts—Chevalier, for instance—but it tillers freely. In consequence of this high-tillering character the crop is frequently better than would be expected when the young plant has been thinned by unfavourable soil, or seasonal conditions in early spring. If it is sown fairly early, say, during March, it generally comes to harvest within a few days of Chevalier sown at the same time. It is specially suited for light and early soils and for growing after wheat. Also, owing to its hardiness, the plant stands up well under adverse early spring conditions in exposed situations, such as the early upland districts of the south-west of England, and it yields better than Plumage under such conditions.

From a very careful study of experiments made at Warminster with this barley I found that it made much more root in proportion to shoot in the quite early stages of its growth.

Although Archer behaved better in what might be termed the vegetative stage of the plant when grown alone, if it was grown in competition with another quick-growing or taller race it suffered. Archer invariably gave a higher yield than Plumage when grown separately, although it was inferior in quality. Experimenting with the two races in 1905 it was found that when they were seeded equally together Plumage almost killed the Archer down. This was due to the fairly obvious fact that Plumage made a quicker start and overtopped the Archer barley before the latter had a fair chance.

Fig. 29 shows the appearance of the straw, length of neck,[1] and of the ears of these two 'pure races', Plumage and Archer, and of their offspring, Plumage-Archer. Fig. 30 shows typical ears of these three races.

[1] Differences in length of straw and of neck in barley are to some extent modified by seasonal and cultural conditions.

PLUMAGE.

PLUMAGE-ARCHER.

ARCHER.

FIG. 30. Ears of Plumage, Plumage-Archer and Archer.

To face page 242

NOTE.—'Pure line' Archer has been replaced by Spratt-Archer. The only reliable cultures of English Archer now obtainable in this country are, I believe, the few square yards grown in the nursery at Warminster. This is unfortunate, as 'place effects' of seed often make considerable differences to crops and in all trials of races the seed should have been grown in as nearly as possible similar environments.

CHAPTER XXIV

HYBRIDIZATION

WHEN the single-line method of increasing the value of existing stocks of barley had wellnigh reached its limit we came to consider methods of crossing new and distinct races by the practice of hybridization (or cross-breeding), i.e. the creation of new combinations by taking two races of the same species which differ in their characters, with the intention of combining the desired qualities of both by artificial crossing.

Uniformity and evenness of sample are more difficult to obtain with hybrids started by crossing because the large number of Mendelian characters possessed by each parent may give rise to a considerable number of combinations in the progeny. Whenever we cross-fertilize and raise a progeny from single plants (even from single plants of the F.4 and F.5 generations) we always sacrifice uniformity to some extent. There is no hybrid race in which the individuals are uniform in all inherited characters. The only thing that really matters is that the lack of uniformity should not be prejudicial to the value of the race, as compared with other, possibly more uniform, races. But we do get with our hybrid races approximate uniformity, higher productivity and better quality of grain if our methods are systematically directed to those ends.[1]

I do not know of any hybrid race which is as uniform in respect of early habit and straw characters as are Plumage and English Archer, both raised from selected plants of old races with no record of any hybridism in their past history.

The following table illustrates a comparison between parent and hybrid races:

[1] The term 'hybrid' signifies that the single plant ancestor was one of a family originated by a cross-fertilization, as distinct, say, from Beaven's English Archer or Plumage, two of the few surviving races selected from a single plant not cross-fertilized.

TABLE XXXVII. Warminster Nursery Chequer-board, 1913.[1] Comparing Hybrid Races with Parent Races

Averages of 20 plots of each of four races	Parents		Hybrids	
	Plumage	English Archer	S.145	145/46
Average number of plants per square yard	95·9	98·8	97·7	102·0
Average weight of ears per plant (grammes)	3·08	3·03	3·06	3·13
Average weight of straw per plant (grammes)	2·99	2·86	2·82	2·43
Average total weight per plant (grammes)	6·07	5·89	5·88	5·56
Average number of ears per plant .	1·81	1·99	1·93	1·99
Average weight per ear (grammes) .	1·70	1·51	1·59	1·57
Average weight per straw (grammes) .	1·65	1·45	1·45	1·23
Average total weight of ear and straw (grammes)	3·35	2·96	3·04	2·80
Average number of ears per square yard	173·6	197·2	188·4	202·8
Average weight of plants per square yard (grammes)	581·8	582·8	575·4	566·8
Average ratio of parents to hybrids .	100		98·8	97·4
Average yield = weight of ears per square yard (grammes) . .	295·2	297·8	300·7	318·6
Average ratio of parents to hybrids .	100		101·6	107·6
Average M = ears percentage of plants	50·7	51·1	52·2	56·2
Average ratio of parents to hybrids	100		102·5	110·5

This table shows that some hybrid races yield better than either parent race when grown under parallel conditions. In the above case this was confirmed in subsequent years, and it is evident that the improvement is due to the higher migration coefficient (M).

Hybridization of any wide-apart races produces thousands of mongrel plants, all differing in some characters (often minor ones), only probably different by repeating cultures for several generations. I have never had any success in

[1] The chequer-board method is fully described in the following chapter.

crossing wide-apart races even if they were of the same species.

I have in fact found that the only useful method of cross-fertilization is to follow the purely empirical practice of all successful breeders of domestic animals, namely, to select as parents only those individuals each of which can claim an ancestry of proved economic worth and which also are not widely dissimilar in character.

Fig. 32 portrays the result of cross-fertilizing at Warminster in 1903 two very widely differing races of barley, and shows how great the number of the intermediate forms of the F.2 generation may be.

The parents (Fig. 31) were:

1. *Hordeum spontaneum*: from a culture received originally from the Botanic Garden of St. Petersburg. It had, and its progeny still has, all the characters of one of the races of wild barley as it grows to-day in many Eastern countries.
2. *Hordeum hexastichum*, var. *thyrsoideum*: from a culture descended from a single ear received from Mr. Karl Hansen. It was evidently a 'mutation', for it is different in all the characters of its inflorescence from any other known race and it has remained constant in all these characters since it first appeared.

These two races, although so wide apart in original structure, cross freely, and the hybrid plants almost without exception are fertile. All known forms of barley are intermediate in structural characters between these two extreme forms.

Two fertile seeds resulted from the cross, which gave two plants of the F.1 generation, bearing over 200 seeds. The ears of F.1 are not illustrated. Like those of H. *spontaneum* they dropped to pieces on ripening. Also, like H. *hexastichum*, var. *thyrsoideum*, the individual grains instead of bearing awns had short trifurcate appendages like those of H. *vulgare*, var. *trifurcatum*, which is cultivated in Himalayan districts. (The grain of H. *hexastichum*, var. *thyrsoideum* has no economic value, but it has as stout a straw as any race of barley I have met with.)

Cross of *H. spontaneum*, Koch., and *H. hexastichum*, var. *thyrsoideum*.

FIG. 31.—Ears of parent plants.

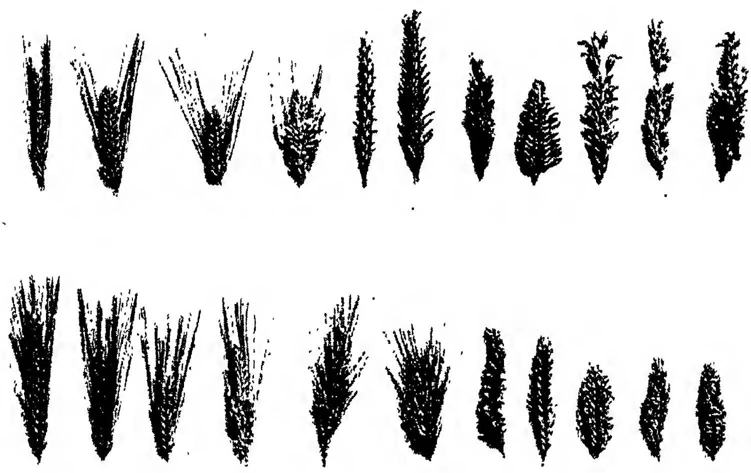


FIG. 32.—Ears of 22 plants of second hybrid generation. F.2.

To face page 246

These seeds of the F.1 generation nearly all proved fertile and produced 230 plants of the F.2 generation. Fig. 32 shows ripe ears of 22 of these plants, but these by no means display all the variable characters of the plants of this generation. Nearly every one of these 22 types of inflorescence occurred on plants differing *inter se* in other respects, namely, in characters of the root, the stem and the leaves [1]; in degrees of fragility of the rachis; and also in physiological characters, such as 'tillering' habit, length of growing period and susceptibility to parasitic diseases.

Progeny of each of the 230 F.2 plants was grown in the F.3 generation and every one of these 230 cultures contained plants differing from each other in one or other racial character. Some progenies of the F.3 plants were grown on to the F.7 generation, and single plant cultures from these were carried on for a few more years. From casual observation I doubt if any two plants of this F.7 generation are absolutely alike genetically: many of them appear to be 'splitting'.

From 200 F.2 plants carried on to the F.4 generation, 20,000 plants were put aside for critical examination. I believe that no two of them were alike in genetic characters. It is, of course, difficult to distinguish between genetic and fluctuating characters in old material, but I think that if they were critically examined by an expert geneticist the conclusion would be that the presence of many hundreds of 'genes' was involved. If the whole of these 20,000 plants had been grown on to the F.7 generation there would have been about 50 millions of progeny and conceivably that number of distinct races.

This experience proved that it is hopeless in practice to expect any useful results from 'wide-apart' crosses even if each parent had some useful racial characters.

These cultures may, however, in future, throw some light on recent neo-Mendelian theories.

[1] It is sometimes overlooked that in addition to the genetic variability of the cereals in respect of the inflorescence, the genetic variability in respect of vegetative characters, viz., root, stem and leaves, and the habit of growth, is also very great. I have had instances of winter barleys sown side by side in the autumn: in one race, no part of any leaf was an inch above ground: some races with quite large shoots were entirely prostrate: whilst plants of another race growing alongside were erect and nearly a foot high. These are undoubtedly genetic characters, and as far as I can see there are all degrees of this vegetative habit.

Sixteen cultures (F.18) of hybrid *spontaneum* × var. *thyrsoideum*, cross-fertilized in 1918, were included in the nursery plots in 1936. All the cultures were the progeny of one F.2 plant (1920). It is believed that the progeny of this cross still continues to split in some vegetative characters. If so, it may be suggested that there is no end to the 'mutability' of hybrids in some morphological or physiological characters.

As an example of the difficulty of breeding for some desired combination of good qualities, even in races of known agricultural value, Fig. 33 shows the ears of the parent plants and Fig. 34 gives examples of the ears of different plants of the F.2 generation arising from a cross-fertilization made in 1928. It was hoped that this might be the first stage in the production of a new hybrid race, having the well-proved good points of both the parent races.

The parents were:

1. Plumage-Archer—H. *zeocriton*, var. *erectum*.
2. F.112—H. *hexastichum*. This six-rowed race was the progeny of a single plant of an old variety selected many years ago and considerable acreages of it have been cultivated.

Most of the plants of the F.2 generation were intermediate between the parents in one or more of the rather widely differing characters of root, stem, leaves and inflorescence. Several F.3 cultures were selected and each further multiplied up to the F.6 generation. None of these cultures was worthy of being taken forward to the next stage, viz., that of chequer-board trials.

Even these two parent races, which both possess very good points, probably differ too much in morphological characters to make it possible to extract from their progeny cultures which would be more valuable than the parent races.

Even if we choose only 'well-proven' parents (as I have done for some years past) it is necessary to grow cultures of F.2 plants separately for at least two or three more generations before selecting those which are likely to be of greater economic worth than their parents. But nursery space is limited, and we can only carry on a limited number to the F.4 and F.5 generations. Mendelism and all its recent elaborations fail

Cross of *H. erectum* and *H. hexastichum.*

FIG. 33.—Ears of parent plants.

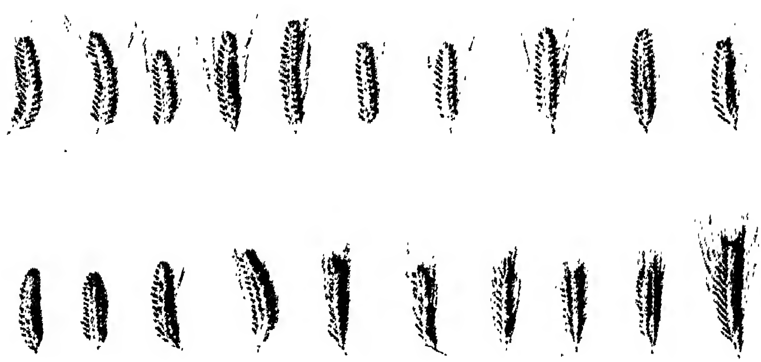


FIG. 34.—Ears of 20 plants of second hybrid generation. F.2.

To face page 248

us here because of the great number of differing characters of the plant which affect either productivity or the quality of the grain, even when the parent plants are not of widely differing races.

The geneticist will generally offer an explanation of the plant-breeder's results after they have been obtained, and even enable him to forecast some of the more simple effects of cross-fertilization, as, for instance, what proportion of plants with black grains will appear in the F.2 generation if the parent plants bore black and white grains respectively. But 'genetics' can do little or nothing to help us at this stage to select cultures for multiplication which will give better results than the parent races to both farmer and brewer, which is our special object.

Imagine an owner of thoroughbreds who has a hundred yearlings and is only prepared to enter one for the Derby. The odds are probably more than 10 to 1 against his entering the best of them and certainly more than 100 to 1 against the one which was really the best winning the Derby two years after, however much the 'genetics' of the problem had been studied. The plant-breeder's position is similar. Plant and animal genetics have much in common if we accept current 'chromosome' theories; but it is a fact that both in plant and animal breeding art as well as science is requisite. Sir Rowland Biffen excels in both and rightly deserves the title of the 'Wheat Wizard'. I am no artist and have had to depend on more laborious and meticulous methods, such as replication of comparative trials, counting and weighing of produce, biometrical analysis, and such laboratory work as my resources have permitted.

Biometrics are useful at all stages of plant breeding and can be applied after, say, 100 plants have been raised. They are more especially applicable to yield in chequer-board and half-drill strip plots.

The Technique of Hybridization and of Selection

The artificial hybridization of barley is a comparatively simple process presenting no difficulty to those familiar with the practice as applied to other plants. It consists merely of first extracting the unripe anthers from a flower of one

plant and dropping on the exposed stigma a ripe anther from the flower of a plant of another race.

The parent plants are referred to in the language of genetics as the F.0 generation. The plant which is grown from the hybrid seed is called the F.1, or first filial generation. This F.1 plant commonly resembles one of the parents more closely than the other, and if several florets of one plant have been cross-fertilized with pollen from any one other plant, and there are several F.1 plants in the next generation, these F.1 plants are generally indistinguishable from each other in their morphological characters.

But each of these F.1 plants may bear 100 seeds and if these are sown—giving 100 plants of the F.2 generation—these 100 F.2 plants will not be all alike if the parents were of different races; some will resemble one parent, some the other parent, and in most cases there will be many differing intermediate forms.

The technique of selecting single plants in an F.2 generation, or of selecting cultures seeded from these plants, has not yet been fully discussed by any writer. It is immensely complicated by the difficulty of distinguishing between the heritable differences and the fluctuating differences arising from external conditions, which always occur.

The method of selection which has been adopted at Warminster is as follows: From the cross-fertilized grain of the selected plants we may get some 10 plants, producing about 50 ears in the F.1 generation. The following year 12 grains from each ear are planted, each being given a consecutive number.

The method adopted for numbering the twelve grains in the F.2 generation planted from each F.1 ear harvested is as follows:

First year.—F.0. Cross made (say, ×14), 10 florets set and 10 grains developed.

Second year.—F.1. Ten grains planted wide apart to give large plants—each plant separately harvested and numbered thus:

×14	Plant 1	producing,	say,	8	ears.
	Plant 2	,,	,,	6	,,
	Plant 3	,,	,,	3	,,
	Plant 4	,,	,,	4	,,
	Plant 5	,,	,,	2	,,
	Plant 6	,,	,,	7	,,
	Plant 7	,,	,,	5	,,
	Plant 8	,,	,,	5	,,
	Plant 9	,,	,,	2	,,
	Plant 10	,,	,,	3	,,

The ten plants giving a total yield of 45 ears.

Third year.—F.2. Twelve grains (1 row) planted from each F.1 ear harvested and numbered thus:

× 14/1/1 = × 14/Plant 1/Ear 1.
× 14/1/2 = × 14/Plant 1/Ear 2.
And so on to × 14/1/8 = × 14/Plant 1/Ear 8.

And so on to the last hybrid which would be

× 14/10/3 = × 14/Plant 10/Ear 3.

This means that a total of 540 grains would be planted, which, after allowing for failures and the discarding of both outside plants, would probably average nine plants per row to harvest = 405 plants.

There are about fifty rows of 12 grains each, which means that we get 500–600 plants in the F.2 generation. The produce of these fifty rows will be 'splitting'; some plants resembling one parent, some the other; and the remainder something between the two. At harvest the two outside plants are discarded: the remaining plants are harvested, weighed and classified, each being numbered. After harvest they are carefully examined and notes taken as to length and stiffness of straw, length and stiffness of neck, weight of straw minus root, weight and type of ear, strength of rachis, ratio of grain to straw and susceptibility to parasitic disease. From the results of these determinations (together with eye inspection [1]) a number of these F.2 plants are discarded: from the remaining produce 12 grains from the best ear of each plant are sown (each row usually alternated with a 'control' race) which produce a total of approximately 4,000–5,000 plants. These are harvested in a similar manner to the previous year's produce and the same determinations are made on the produce of each plant. From this F.3 generation about twenty of the best hybrids are selected for further trials, selection and multiplication—all the remaining produce being discarded. From the produce of the plants selected, four or five of the most promising hybrids are carried on to the F.5 generation. When we have decided which cultures to proceed with (generally less than one in twenty of those raised to the F.5 generation), and when we have about a pound of seed of such a race (or races), we proceed to the next stage of trial and multiplication, viz., the nursery chequer-board cultures. The F.5 generation is considered to be the earliest in which significant results could be obtained with which to compare the selected races. Similar chequer-board (and half-drill strip) [2] trials are required

[1] I attach no value to eye judgement for yield, but it is useful for quality.
[2] For description of the half-drill strip method see Chapter XXVII.

the F.7, F.8 and F.9 generations in order to decide ıether any of the cultures are good enough for distribution. several cases I have selected cultures for further multiplica- ›n in the F.10 generation, and whenever this has been done e new culture has been different in some respect from all e other cultures which have been the progeny of other F.2 ants.

I am of the opinion that single plant cultures started from later generation than, say, F.5 of a hybrid plant, although ; in the case of 'Plumage-Archer 1924' (see Chapter XXVIII, . 299) sometimes superior in respect of certain qualities, are ot on the whole better than aggregates like 'Golden Archer 5/F' (see Chapter XXVIII, p. 301) made up of the progeny f a number of closely similar cultures, all derived from an '.2 plant and selected in the F.3 generation. I think this ıeans that there is so much 'differential response' of race o environment that slight differences in the 'habits' of in- .ividual plants are compensatory. But it is a very abstruse ubject and only practical results can give us reliable :onclusions.

Re-selection from Hybrid Races

Can we continue with advantage to re-select parent plants from a hybrid race in succeeding generations? All animal breeders, and probably all horticulturists, would answer the question in the affirmative. It is their regular practice.

In the case of the cereals, however, the individual seeds in the succeeding generations following an artificial cross are self-fertilized, and according to the Mendelian theory the progeny of the plants which are 'fixed' in the third generation will breed 'true' and not alter in character as long as they go on self-fertilizing, and this theory has been proved to hold good in respect of simple characters in plants.

But, even if the Mendelian doctrine of unit characters is fully admitted, it is quite likely that in any two original parents of two distinct races of any cereal the number of differing characters may be so numerous as to render the number of possible combinations almost unlimited.

There is plenty of evidence that there is a good deal of coupling and linking of characters, but it is possible that some characters may escape from the linkage in future

generations with self-fertilization. Also, there must be a number of 'internal' characters which may be 'splitting', but which cannot be observed by merely inspecting the plants. It is at least open to doubt whether any cereal race at present in cultivation, resulting originally from cross-fertilizing two distinct races, is absolutely uniform in all its racial characters. If it is not uniform, it is certain that the aggregate will alter in character in future years from the competition of individual plants under field conditions. Unfortunately the best grain-forming individuals do not always survive and so the race may deteriorate in this respect.

The question whether any improvement will result in any particular case from the re-selection of individual plants in successive years is of course another matter. Our present knowledge of hybrid barleys leads us to conclude that, whatever the origin of the race, in order to retain its uniformity it is very necessary and desirable to re-select individual plants in successive generations in order to eliminate the minor differences in structural or constitutional characters and to raise from these single plant cultures 'selected hybrid races'.

Recent research in genetics favours the general conclusion that inbreeding is desirable when (but only when) both parents are free from any marked unfavourable character.

Unfortunately, in the case of cereals, the process of effectively selecting by observation of progeny from amongst the progenies of hybrid plants is very costly, and quite unprofitable as a commercial proposition, if all the necessary conditions are fulfilled. For this reason, perhaps, the necessary conditions have often been unfulfilled and as a consequence many hybrid races of cereals which have been introduced into general cultivation have, in the past, proved to be less useful than those which they have displaced.

It is the plant-breeder's job to produce a race which will combine the desired characters of both parents, and if in the process some sacrifice of uniformity in unessential characters is made, it may be justified if overbalanced by the particular combinations which give extra vigour and productivity in the plant, with the desired quality of grain.

CHAPTER XXV

CAGE EXPERIMENTS AND THE CHEQUER-BOARD METHOD

THE object of the nursery experiments was twofold, namely, (1) to increase the acreage and improve the quality of the barley of this country; and (2) to maintain the character of barley as brewing material (for which purpose it is mainly used) by studying the quality of the grain as well as the yield per acre.

With the exception of cultures grown from a few commercial samples of imported barleys, all the barleys in the nursery (and in the field) have a recorded pedigree originating from single plants collected from outside sources, or selected from previous cultures at various dates since 1894.

I only allow seed of such races as I am myself satisfied is in some respect superior to that of existent races to be put out, which means that about 99 per cent. of the races which are raised are 'scrapped'—often after many years of systematic trial.

CAGE EXPERIMENTS

Previous to the introduction of the chequer-board cultures two races had been compared in the cage by sowing alternate rows. In 1905 Archer and Plumage were compared by this method. In addition to sowing alternate rows, one-tenth of an acre of each race was grown outside the cage in order to make a comparison. The result was that, whereas Archer gave slightly better yield outside the cage, Plumage yielded 20 per cent. better than Archer within the cage.

The correlation between the yields was significantly negative owing to the two races being grown side by side. Plumage, being a taller barley than Archer, shaded the latter and probably took more nutriment out of the soil.

This experiment showed clearly that a comparison of adjacent rows with interference of this kind was useless, and to overcome this difficulty, and further to ascertain whether

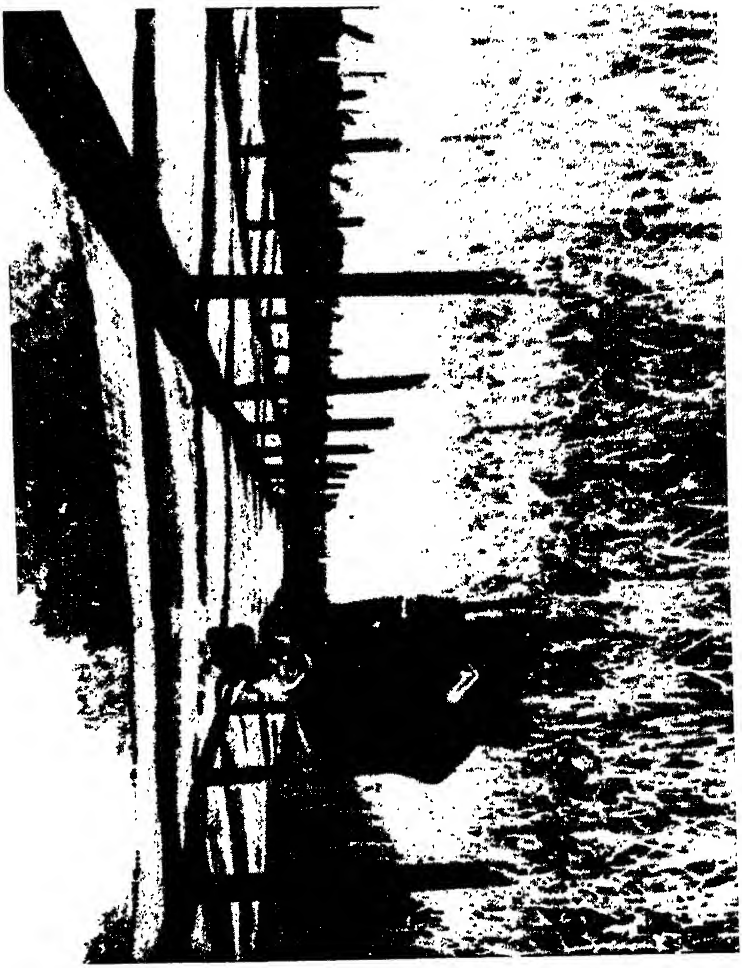


FIG. 35.—The barley cage.

To face page 254

in widely differing environments a certain race will generally be more profitable to the grower than another, I devised in 1909 a standard method of sowing which became known as the 'Chequer-board' culture.

Chequer-board Method

In 1910 the first application of the chequer-board method of yield trials was made in the Warminster nursery. This method has been continuously used since that period, with the exception of the two latter years of the 1914–18 War.

At the start only four races were used for comparison, 8 plots for each race = 32 plots, but it soon became apparent that this was not a sufficient quantity to give a good comparison as between the races and accordingly, dating from 1912, the number was increased to eight, one of which was used as a 'control' race.

These eight races are 'chess-boarded' in the centre of the nursery. The disposition of the plots of the races is such that they occur more or less at 'knight's-move' intervals, the object being to equalize the conditions for each race.

As soon as sufficient seed is obtained, the eight races are sown by hand in plots of 16 sq. ft. each, of which only the central square yard is harvested. The seed of each race used is grown, as far as possible, in the nursery in the previous year. The individual seeds and plants in each plot are equidistant: the seeds are planted at 2-inch intervals in the rows with a 6-inch space between the rows, which is somewhat more than the average soil space per plant in fields of barley. There are 108 seeds per square yard (=about 4 grammes), which is approximately half (or less) the number generally sown in the field.[1] One or two thus sown are old 'pure races'; and the others are hybrids grown up to this stage from the progeny obtained by the cross-fertilization of two 'pure races'. There are 12 plants to each square foot, which is about the average number of surviving plants in

[1] This is equal to 19,360 grammes per acre (=42½ lbs.).

The usual field sowing (and in field experiments) is about 140 lbs. (=2½ bushels).

The average number of surviving plants per square yard in *chequer-board* cultures is about 95 (=approximately 460,000 plants per acre).

The average number of surviving plants per acre in *field plots* is approximately 680,000.

field cultivation. There are usually 20 plots of each race, making 160 plots in all.

By this method the errors of experiment due to variable soils of the plots are, as far as possible, eliminated. Needless to say, results so obtained are not invariably confirmed by subsequent field trials, although they usually are. It is certain, however, that we shall never get cage hand-planted crops to compare strictly with field crops grown alongside, and it is obvious that the results obtained cannot afford conclusive evidence of the comparative value of races grown under normal agricultural conditions. Hand - cultivated methods are only (economically) useful in the early stages of plant breeding in order to afford indications of probable quality of produce; and they do provide good indications of comparative potential capacity for 'tillering' and 'migration' as between races; and these are two important factors of productivity.

To maintain the fertility of the cage artificial manures are generally used.

A plan of the lay-out of the chequer-board plots is shown opposite (Fig. 36), and a plan of each plot (Fig. 37).

All the harvesting work is done by hand. The produce of each plot is separately harvested; the plants are pulled up and counted, and the roots cut off; the ears are counted and bagged separately for each plot; the straw of each plot is separately bundled; the number of plants and of ears of each plot is recorded.

After the whole produce has been dried to approximately 12 per cent. moisture on a kiln, the ears and stems of each plot are separately weighed; the average number of weight of ears per plant, the average weight per ear, and the ratio of ear weight to plant weight are computed for each plot.

Subsequently laboratory determinations of nitrogen content and 1,000 corn weight are made; and such biometrical work begins as is useful for interpreting the data. Since there are a hundred countings and weighings and many hundred deduced ratios for each of the eight races in each chequer-board, it will be seen that there is abundant material every season for biometrical analysis.

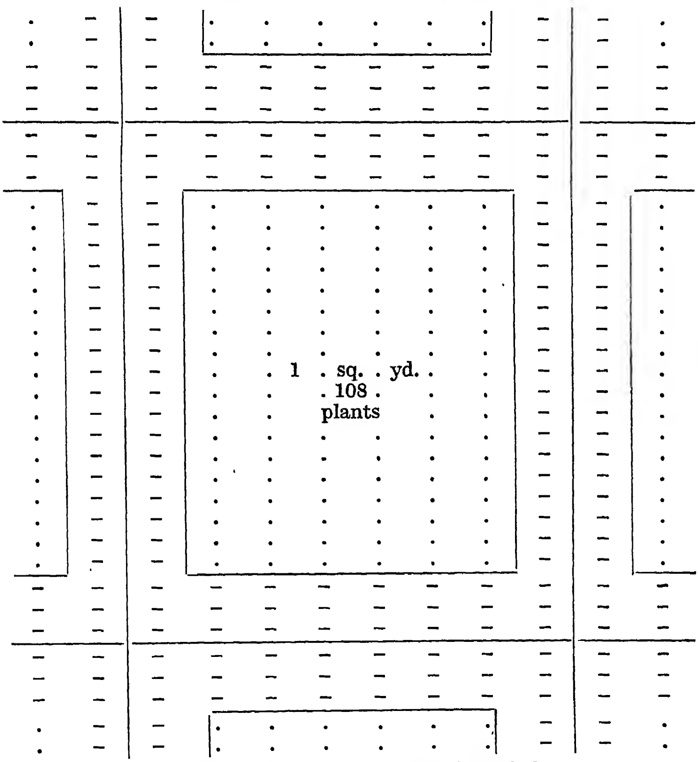
I now have in my possession the records of over 30 of these chequer-boards, amounting to about 5,000 plots. Six

FIG. 36.—Plan of lay-out of Warminster Nursery Chequer-boards.
8 races. 20 plots each—160 in all.
(In some years there were only 16 plots of each race.)

6	3	8	5	2	7	4	1	6	3	8	5	2	7	4	1	6	3	8	5	2	7	4	1	6	3	8	5	2	7
7	4	1	6	3	8	5	2	7	4	1	6	3	8	5	2	7	4	1	6	3	8	5	2	7	4	1	6	3	8
8	5	2	7	4	1	6	3	8	5	2	7	4	1	6	3	8	5	2	7	4	1	6	3	8	5	2	7	4	1
1	6	3	8	5	2	7	4	1	6	3	8	5	2	7	4	1	6	3	8	5	2	7	4	1	6	3	8	5	2
2	7	4	1	6	3	8	5	2	7	4	1	6	3	8	5	2	7	4	1	6	3	8	5	2	7	4	1	6	3

Numbers 1 to 8 represent races.

FIG. 37.—Plan of individual Plots.



. plants harvested. – plants discarded.

different determinations are made on the produce of each and a mass of material has been worked out from the

available data, including hundreds of correlation coefficients, which it is hoped will serve to indicate which are the factors of productivity.

The manner in which the chequer-board results are recorded and analysed with a view to selecting the best races from these preliminary cultivations is set out in Table XXXVIII.

Eight races were under comparison and each figure for each race is the average of the 20 figures obtained by counting the plants and weighing separately the straw and ears on each of 20 square-yard plots. Races numbered 1, 6 and 7 are hybrids, all having the same ancestry. The others are 'pure line' Archer barleys, grown up from plants selected generations previously. Of these, No. 4 is one of the parents of the three hybrids. All the five Archer races are constant in type and present only very slight differences in appearance.

Column 7 of the table gives the percentage of the ratio of grain to straw (migration coefficient factor) and column 10 gives the yields of grain as compared with Race No. 1 taken as 100.

The 'probable errors' of the migration coefficients (M) of each race shown in the table are very low. The migration coefficients of each of the 20 plots of each race differ so slightly from each other that it becomes practically certain that each of these eight averages in column 7 is within a small fraction of 1 per cent. of those which would be obtained by repeating the experiment any number of times.

If we compare Race No. 1 with Race No. 4—i.e. a hybrid with one of the parents—the difference of the two migration coefficients shown in column 7 is that between 48·3 and 46·6 per cent. respectively, viz., 1·7 per cent. Now, according to the laws of probability, with a 'probable error' of something less than 2 per cent. the odds are a good deal more than 1,000 to 1 that this is not merely a chance difference.

On the other hand, if we take the figure of either column 6 or columns 9 and 10, representing the actual average weights of the total produce and of the ears, and if we take into account the figures for each of the 20 plots, of which these are the averages, then we see that these figures are subject to a very much higher 'probable error'. The 'range' of the weights on each square-yard plot is something like 30 per

TABLE XXXVIII.—Warminster Nursery Chequer-board, 1912. Averages of 20 square-yard plots of each of 8 races of barley

1	2	3	4	5	6	7	8	9	10	11
Race	Average number of plants per square yard	Average number of ears per plant surviving at harvest	Average weight per ear, straw and ear	Average weight per plant, straw and ears	Average weight of total produce per square yard	M weight of ears to 100 total produce	Average weight per ear	Average weight of ears per square yard	Weight of ears on 20 square yards, compared with Race 1 taken as 100: Weighed	Calculated from M
	N		grammes	grammes W	grammes	per cent.	grammes	grammes $\frac{N \times W \times M}{100}$		
1. ×14/145	102·9	2·04	2·57	5·22	537·8	48·3	1·24	259·7	*100*	*100*
2. Archer 7[a]	104·4	2·09	2·48	5·18	540·4	47·9	1·19	259·0	*99·8*	*99·4*
3. Early Archer	104·6	2·14	2·41	5·17	540·1	47·5	1·14	256·3	*98·8*	*98·4*
4. English Archer	103·6	2·12	2·51	5·32	545·9	46·6	1·14	255·9	*98·6*	*96·5*
5. Irish Archer	103·9	2·07	2·48	5·14	535·0	46·2	1·15	247·0	*95·5*	*95·6*
6. Biffen 2	105·4	1·81	2·74	4·96	523·4	46·8	1·28	244·8	*94·3*	*97·0*
7. ×14/75	103·0	1·99	2·61	5·20	534·9	45·3	1·18	242·4	*93·5*	*93·8*
8. Cannell Archer	102·7	1·91	2·75	5·24	538·2	45·2	1·23	240·6	*92·5*	*93·6*
Probable errors of each average				..	..	± ·2	..	..	± *3·0*	± *·4*

cent. on each side of the average, and it might easily be a matter of pure chance that there was a difference like that shown in the table of 1·4 per cent. only in the average yields of the 20 plots. It is no more than even betting that such a difference would be shown if the same experiment had been repeated a much larger number of times. An equal difference in the other direction would be just as probable. No conclusion could be drawn from this result if it stood alone.

But the case is entirely altered when we find that as between these two races there is a definitely measurable difference in the ratio of grain to straw, as shown by the 'migration coefficient', and that, as shown by columns 10 and 11, yield and migration are closely parallel.

It follows that if we can prove that there is a general conformity between the order of the migration coefficients and of yields of grain, when races are compared under the same conditions, then when the differences in yield are (as they generally are) within the limits of experimental error, we shall do better in the long run if we attach special importance to this character of good migration for the purpose, in the first place, of selecting individual plants, and in the second place, for the purpose of assessing the comparative values of the small aggregates of each race obtained within the first few generations.

If the scale of the real differences between the races which we are likely to produce were 10, or 15, or 20 per cent. we could no doubt demonstrate them by simply weighing the grain from a small number of plots. But differences of this order are not in the least likely to come at 'one fell swoop'.

Columns 3 and 8 show no very wide differences in either tillering capacity or ear weight. Somewhat wider inherited differences than are here shown occurred between other races than these, but generally the differences to be expected are in about those proportions when, as in this case, we start with races which have all been selected for high yield.

The differences between individual plants, even in cultivations of this kind with equal soil space per plant, are of course greater than these average plot differences. Also, some ears weigh less than 1 gramme (1/28th of an ounce) and some more than 2 grammes. These latter wide differences in tillering and ear weight have nothing necessarily to do with

TABLE XXXIX.—Warminster Plots, 1938. Chequer-board Trials

Highest in merit in **heavy** type. *Low* N. indicates good quality.

Races	Estd. avg. weight grain per acre, cwts.	Avg. no. surviving plants per sq. yd.	Avg. no. ears per plant	Avg. weight per ear, grammes	M per cent.	Avg. N. per cent. dry grain
	(1)	(2)			(3)	
P.A.1935 .	27·0	103·2	2·56	1·27	**56·7**	1·36
G.A.35/F .	26·0	102·6	2·68	1·18	53·6	1·40
× 54/12 .	25·7	102·8	2·59	1·21	54·5	1·36
S.A.37, No. 3	26·5	102·3	2·69	1·20	54·0	1·36
G.A.35/51S .	27·0	**104·3**	**2·80**	1·15	53·8	1·37
× 54/13 .	**27·7**	103·6	2·72	1·23	54·1	1·35
× 54/12/3 (C)	27·0	102·2	2·525	**1·31**	55·2	**1·26**
× 54/12/3 (F)	27·0	103·3	2·53	1·29	55·7	1·27
Averages .	26·7	103·0	2·64	1·23	54·7	1·34

(C) = cage-grown seed 1937. (F) = field-grown seed 1937.

TABLE XL.—Warminster Plots, 1939. Chequer-board Trials

Highest in merit in **heavy** type. *Low* N. indicates good quality.

Races	Estd. avg. weight grain per acre, cwts.	Avg. no. surviving plants per sq. yd.	Avg. no. ears per plant	Avg. weight per ear, grammes	M per cent.	Avg. N. per cent. dry grain
P.A.1935 .	21·2	**103·2**	2·11	1·22	50·1	1·42
G.A.35/F .	19·5	103·1	2·18	1·09	45·4	1·54
× 54/12 .	18·9	100·0	1·99	1·18	47·3	1·48
S.A.37, No. 3	19·1	101·85	2·17	1·08	44·5	1·51
G.A.35/51S .	19·4	101·7	2·15	1·11	46·1	1·61
× 54/13 .	19·9	99·85	2·06	1·21	47·2	1·52
× 54/12/3 .	**21·4**	100·4	2·05	**1·29**	50·0	**1·35**
Abed Kenia	16·8	95·2	**2·35**	·91	**51·9**	1·60
Averages .	19·5	100·7	2·13	1·14	47·8	1·50

The manuring in these experiments was 3 cwts. superphosphate, 3 cwts. kainit, 1½ cwts. sulphate of ammonia, per acre, sprinkled on and raked in before sowing.

(1) These figures are obtained by multiplying grammes per square yard (ears) by ·08 and assuming that rachis and awns weigh 16·3 per cent. of the weight of ear. The ears are weighed with about 12 per cent. moisture, but the average moisture of English barley is about 15 to 16 per cent.

(2) 108 seeds per square yard are planted.

(3) M = the migration coefficient, i.e. weight of ears as a percentage of the weight of the entire plant (excluding roots).

RACES GROWN IN CHEQUER-BOARDS, 1919–40

Races	Parentage	Year of F.0
1919. Plumage-Archer × 14/145 (w)	Plumage (H.343) × English Archer (4)	1905
Plumage-Archer × 14/145/46/55 (w)	Plumage (H.343) × English Archer (4)	1905
English Archer (n).		
Plumage-Archer 14/53/3 (n)	Plumage (H.343) × English Archer (4)	1905
Plumage (w).		
Plumage-Archer × 14/47 (w)	Plumage (H.343) × English Archer (4)	1905
Biffen's 59/7.		
Plumage-Archer × 14/135/6 (n)	Plumage (H.343) × English Archer (4)	1905
1920. × 22/33/3/4/6 (w)	Plumage (H.343) × English Archer (7)	1911
× 23 (w)	× 14/75/11/4 × X14/145/51	1912
1921. Spratt-Archer 37/6 (n)—ex Hunter	..	1908
Garton's 1917—ex Garton.		
× 22/33/3 (w)	..	1911
Biffen's 57—ex Biffen.		
Plumage-Archer × 25/1 (w)	× 14/145/46 × Biffen's 59/7	1916
Plumage-Archer × 14/47 (w)		1905
1923. × 23/9/7 (w)		1912
1925. Garton's 907—ex Garton.		
1927. × 34 (n)	145/14/46/55 × Spratt-Archer 37/6	1923
× 35 (w) and (n)	Spratt-Archer 37/6 × 25/1	1923
× 36a (n)	F.118 (Mesopot.) × P.A.1924	1923
× 36b (w) and (n)	F.118 (Mesopot.)X × 14/145S.	1923
× 37 (w) and (n)	F.118 (Mesopot.)X × 14/146S.	
× 42 (n)	135/6 × 25/1	1925
× 43 (n)	135/6 × P.A.1924	1925

inheritance, but are for the most part purely adventitious, and would probably not be repeated in the next generation if cultivations were re-started from the grain of these individual plants. One individual plant growing under normal field conditions is frequently twenty times more prolific than its neighbour, although the seed may have come from the same ear. There is plenty of evidence that there is no true inheritance of characters acquired from the environment in the case of the cereals.

Not much value can be attached to one year's trial of any race of barley, especially the first year when the seed-grain is necessarily not comparable in physical character to that of the races which have been grown under similar conditions in previous years.

More recent results of respective races in the chequer-board trials are given in the tables on p. 261.

The chequer-board trials are not the final stage in the sorting out of new races. We have to verify our conclusions by field trials in successive years under varied soil conditions, and, if possible, in fairly widely separated districts.

Incidentally, it may be noted that the progeny of races selected both at Warminster and by the Department of Agriculture in Ireland were all selected by precisely the same methods as are still adopted, viz., chequer-boards and half-drill strips. The two hybrid races, Plumage-Archer and Spratt-Archer, both originated from cultures selected by these methods, and each of them in one locality.

In the case of Spratt-Archer, after several races had been selected by the chequer-board method, field trials were carried out over many and widely dispersed districts in Ireland for several successive years before the stock of one of them (37/6) was released for distribution in 1922. I had no such advantage for the comparison of Plumage-Archer with other races in Great Britain before the stock was released in 1914.

[*Details of the work (above referred to) and of the examination of the races tested for malting quality by Messrs. Guinness' scientific staff are given in Dr. Hunter's book,* The Barley Crop (1926), *and critically discussed in 'Student's' paper, 'On Testing Varieties of Cereals'* (1923).]

CHAPTER XXVI

FIELD TESTS OF NEW RACES

It will be convenient to use some one word for the aggregates which are dealt with in 'variety' trials. New productions are generally aggregates of plants the individuals of which have a common ancestry, and in 'variety' trials we are only concerned with the inherited characters of the aggregates. The most descriptive term to apply to any aggregate under trial therefore appears to be *race*, indicating the progeny of single plants, or of a selected plant of an old variety.

Some aggregates originating from selected individual plants having a hybrid ancestry, although apparently uniform in all their inherited characters, ultimately prove to be more or less variable and this fact must be recognized in interpreting results of field trials.

It is very improbable that any new race will be produced which will give a higher yield of grain per acre than any other race under every condition of soil, season and cultivation.

In Great Britain there are no wide areas of uniform soil. The lay of the land and the dip of the strata combine to make uniformity impossible. There are doubtless many farms of 500 acres, or more, in Great Britain on which the soil is so variable that no one race of any species of agricultural plant is the best race for all parts of the farm.

The plant breeder is limited in the early stages of the production of new races by the type of soil of his breeding plots and by the average climatic conditions of his station. The comparative yields and quality of a particular race obtained at a station in the West of England, say, on the Upper Greensand with an average rainfall of 36 inches, may be quite different from those obtained, say, on the boulder-clays of East Anglia with a 24-inch rainfall. So it follows that the plant breeder's original determinations of relative productivity, however correct for his own conditions, will not necessarily always be applicable to other localities.

Seasonal effects, even in a limited area, are very diverse.

These, together with the necessarily variable methods of manuring, crop rotation and tillage, may suit one race of a species better than another. Moreover, in some localities a quick-growing race may be necessary in the average of a series of years, as, for instance, the quickly maturing 'Scotch Common' barley in Aberdeenshire. As a general rule, the more slowly maturing races will be the most productive, but superior yield may have to be sacrificed if in, say, one season out of three, there is a chance that the crop would fail to ripen.

All that can be usefully accomplished in any one year in the way of testing new races is to make accurate comparisons in respect of economic value, taking both quantity and quality into account, at different stations selected for typical differences both of soil and of average climatic conditions.

If it were desired to obtain systematic knowledge of the suitability of existing races to localities, no better plan could be adopted than that organized some years ago by the Essex Farmers' Union, co-operating with the National Institute of Agricultural Botany, to which reference has been made (Chapter V, p. 47).

In the case of new races the prospective grower will have to rely on the experience and testimony of those who produce, multiply and distribute the original stock. The extra outlay on a few bushels of seed, which is all that is needed to stock a farm over a few years, will probably be money well spent. Of course there will sometimes be disappointments in the choice of race made for a particular type of soil. On the other hand, if the grower gets, as he may well do, a substantially increased return due either to yield or to quality, or to both, the increase may easily be equal to the rent of the land and he may make much more than this for a few years by the sale of some of his produce for seed.

Now the position of the plant breeder is that unless he is very lucky the cost of producing a new race, which appears to have some definite advantage in its favour, is many hundreds of pounds, and if he proceeds at his own cost to field trials in different localities one of two things happens, either the race gets into other hands and he gets no return, or he must establish an extensive organization for both multiplication and control. In the latter case he runs the risk of having to incur these costs and may after all find that

his new race, which promised so well, is 'not good enough', in which case it should be 'scrapped', because the dissemination of inferior races is a disservice to agriculture.

It is, of course, not necessary to test a great number of races in a great number of localities and over a long series of years. Fortunately there are certain racial qualities, the presence or absence of which can be demonstrated by the plant breeder himself in a few years in one or two localities on small areas, and which may reasonably be expected to hold good under a wide range of external conditions.

The technique of experimental plot cultures has been greatly improved in this country and has in fact been revolutionized during the past few years.

Further investigations of the factors of productivity and of quality, together with elaborated nursery methods, will surely lessen the number of new races which are considered worthy of being carried forward to the stage of field testing.

The problem of testing the comparative yield, per unit area of the ground, of a number of different varieties of the same plant has been written up, amongst others, by Engledow and Yule (1926); and the question of the variation and correlation in yield has been investigated, and the results published, by Gustav A. Wiebe (1935).

In view of the admitted inevitable heterogeneity of any area, large or small, in respect of supply of plant nutrients, there are two primary requirements for trials of new races, viz., (1) sufficient replications, and (2) avoidance of bias in favour of, or against, any one of the races tested.

My own estimate from a survey of existing evidence is that to obtain a 'standard error' of less than 2 per cent. as an estimate of the average weight of produce on unit area (and less is of little value) it is desirable to have at least sixteen replications, whatever 'lay-out' is adopted.

Whatever may be the improved characters at which the plant breeder aims and hopes to obtain, the first essential in systematic comparisons on the field scale is that each comparison shall be, as far as is possible, free from errors of experiment, and the next essential is that some reliable estimate should be made of the probable extent of errors that are unavoidable.

It will naturally occur to some readers that if cultivations are carried out either on the nursery scale with an extensive multiplication of small plots to eliminate experimental error, or continued on field plots, where, however, the experimental error is often greater, the object of the comparisons is attained when the grain on equal areas of each race has been weighed. If we can eliminate experimental error, this is the final test; but this business of yield testing is far more difficult and complex, and in practice far more erratic, than is commonly supposed.

The following table shows the recorded weights of two races of barley grown at Woburn in 1912. The difference between the plots of the same race are in some cases over 40 per cent., and if the plots are grouped in fours the difference between the two races at one end of the field is 5 bushels and at the other end of the field 10 bushels per acre.

TABLE XLI.—R.A.S.E., Woburn, 1912. Field Plots—Barley
Comparison of two races alternated in strips of 1/17th acre

Race		Bushels per Acre	
A		46·3	
	H		35·8
A		48·3	
	H		39·4
A		38·8	
	H		32·6
A		47·8	
	H		34·0
A		34·7	
	H		30·3
A		40·9	
	H		41·0
A		45·0	
	H		37·2
A		52·0	
	H		44·4

It has sometimes been tacitly assumed that if a set of trials of the same races are carried out at a number of stations on different soils the average results obtained give figures

which are more useful than those obtained at any one station. If, as rarely occurs, one race gives better results than all the others at a number of stations there is no doubt a probability that it would have given comparatively good results under still other sets of conditions in the same season. What generally happens is that the order of merit varies at different stations in the same season and in different seasons at the same station. For this reason the averaging of results obtained at a number of stations, whilst useful, is at best of limited value. For example: it is not of much use to a grower in Norfolk to be told that a certain race of any cereal grown in, say, Shropshire, or even at several other stations, has given comparatively high yields if the external conditions at all the stations are different from his own.

If in a comparison of yield on different plots at any station in the same year the errors of experiment exceed the observed differences between the yields of the race under comparison, the results of that particular trial are valueless as yield trials. In variety trials, as hitherto carried out, the probable errors of the weights of grain have often been greater than the observed differences. Also, unfortunately, the existence of these probable errors has often been ignored in published reports.

Experimental Errors

Errors of experiment in variety trials are of two orders: 1. Systematic and generally avoidable. 2. Casual, and not generally avoidable.

1. To the first class belong:

(1) *Character of Seed.*—A necessary precaution which has often been neglected in trials is to make sure that the parcels of seed of the different races under comparison are equally representative. Very considerable differences in yield arise from differences in the physical, germinative and other non-racial characters of the parcels of seed sown. These should not be neglected.

The function of a seed is to give the individual plant a start. Much depends on a good start, and races should not be irregularly handicapped in this respect.

The only practicable method of eliminating this probable source of error is to use seed of all the races under trial which

has been grown and harvested the previous year under uniform conditions, and in case there is any substantial difference in moisture content it would be preferable that all the parcels of seed should be kiln-dried to an equal moisture content.

A very good parcel of seed of an inferior race of a cereal will sometimes give a better crop than an inferior parcel of seed of a better race, but there is no evidence that this accidental quality of the seed would be transmitted to the next generation.

(2) *Admixtures.*—Another systematic error arises if any substantial admixture occurs in the seed of any race under trial. A very small percentage of admixture may be regarded as negligible. One per cent. of 'rogues", if of an obviously different race of the same species, will show quite forcibly when the crop is ripe, but if the 'rogue' plants are only 10 per cent. less or more prolific than the rest, the differences in yield due to them will only amount to one-tenth of 1 per cent., which is negligible.

2. To this class belong:

Numerous Sources of Error.—These include soil variations due to a multitude of causes extending over large or small areas, such as those due to previous cropping and manuring, soil bacteria, etc.; variations in sub-soil and in natural or artificial drainage; contour variations, such as slopes or furrows; irregular shading or uneven exposure to wind; patches of weeds of all sizes; inroads of insects, vermin, birds, etc., in patches. It is quite impossible to exclude these sources of casual errors and they may occur in either small or large patches. Their occurrence may be regarded as chance events and they may all be lumped together because there is only one way of discounting them, viz., to arrange and multiply the plots of each race at each station in such a manner as to give an approximately even chance of getting the same proportion of good and bad patches, and at the same time to keep the races to be compared as close together as possible in order to secure general similarity of soil conditions.

On account of these unavoidable casual errors the yields of cereals cannot at present be compared with the accuracy obtainable in physical experiments in the laboratory. With the help of the statistician, however, we may make steady approaches in this direction. The value of reliable results

when they can be obtained is sufficiently great to justify the attempt.

Probable Error of Yield Trials

Every farmer knows that he cannot obtain a fair sample of the grain threshed from a stack by taking a handful out of one bag. Neither is it possible to find the yielding capacity of a parcel of seed by sowing it on any one patch of ground, large or small. Still less is it possible to estimate the difference in the yielding capacity of two parcels of seed by sowing each of them on a single plot, even if the plots are side by side. To obtain sound comparisons, at any one station, it is necessary to average the results of a number of plots of each race. Having done this, if we have excluded systematic errors, we can calculate by an arithmetical device based on the laws of probability applicable to chance events the probable error of the average results. Obviously the probable error of an average is likely to be less than that of any one plot, and the greater the number of plots the smaller is likely to be the probable error of the average.

Briefly stated, probable error is an average error computed in a particular manner in order to afford a measure of the unreliablity attaching to any average of results by reason of the operation of chance conditions.

The degree of unreliability indicated by any probable error depends on the size of the probable error in proportion to the quantity to which it refers. For instance: if the probable error of a difference between two averages of, say, 5 per cent. is as much as 3 per cent., it is an indication that the difference of 5 per cent. is one that might easily be due to chance conditions. If, however, the probable error of the same difference is only 1 per cent., it would be extremely improbable that such a difference (5 per cent.) arose entirely from chance conditions. If in comparing the produce of a series of 'control' plots of an established race 'C' with a corresponding series of a new race 'A' the results were:

$$\text{'C'} = 100. \quad \text{'A'} = 105 \pm 1{\cdot}0 \text{ per cent.}$$

(where $\pm 1{\cdot}0$ stands for the calculated probable error as a percentage of 'C') we could be practically certain that the difference in favour of 'A' was not a chance occurrence.

The following may be taken as a rough standard of the reliability of any comparison such as we are considering: if an observed difference between two averages, each of a considerable number of cases, is more than four times the probable error of the difference, the difference may be regarded as '*significant*' in the sense that it is extremely unlikely to have arisen from the operation of chance events.

Since it is useless to expect a very rapid rate of advance in the yield of cereals from the breeding of new races, and as it is highly desirable that published conclusions should have a high degree of reliability, a 'fine sieve' is required through which to sift the results of trials. It is therefore suggested that a probable error of 1 per cent., or less, in weight of grain should be aimed at in the difference between any two races at any station in any one year.

The plant breeder usually proceeds year by year somewhat as follows:

1. *Single plants of different races with equal soil space per plant.*—I find that with 12 sq. in. soil space per plant, with all the plants of the same race, and comparing adjoining plants, the differences run from zero up to a quite indefinite maximum; the probable error of the percentage difference is somewhere about 80 per cent. of the average weight of two adjoining plants. A difference of 300 per cent. between two adjoining plants is therefore not conclusive evidence of any racial difference, but may be due to conditions external to the plant. The probable error is much greater even than this for single plants under field conditions with necessarily wide differences in soil space per plant. The foregoing illustrates the practical impossibility of selecting single plants for racial productivity. Incidentally, it also shows the great difficulty, if not impossibility, of adapting pot-culture methods to estimates of productivity, except in respect of very great differences.

2. *Rows of twelve plants with equal soil space per plant.*—The probable error of the difference between two averages of, say, 12 *row* weights is likely to be about 10 per cent., and comparisons at this stage may afford the plant breeder some slight, but very uncertain, indication of racial productivity.

3. A chequer-board of plots—each planted with the same

number of seeds with equal soil space per seed. (This method has already been described in detail.)

Proceeding now to systematic attempts to estimate the magnitude of the probable error to be expected in field trials, Wood and Stratton (1910) from a very large number of published results estimate that the probable error of single plots of any size over 1/40th of an acre is generally about 5 per cent. of the produce of the plot. This gives a probable error of 7 per cent. as that which may be expected when comparing any two adjacent single plots.

This is fully confirmed by Mercer and Hall (1911), and in addition they give a description of the most elaborate experiment of which there is any record in this country with the object of determining the number of plots required to be averaged to produce a prescribed probable error.

An acre of wheat of one race selected for apparent uniformity was divided at harvest into 500 equal rectangular plots and the grain and straw from each plot was weighed. This was a great undertaking—only possible at such a station as Rothamsted. The mass of figures was very thoroughly investigated on statistical lines, not only by Mercer and Hall, but also by 'Student' (1911) in an Appendix to this paper, in which a still more elaborate statistical method was devised, and shown quite clearly to lead to a further reduction in the probable error.

In this experiment the actual difference in the weight of grain between the two half-acres on the east and west of the acre was 8·3 per cent. If, therefore, this acre of ground had been used for a trial of *two* races—one single half-acre on the east and one single half-acre on the west side—there would obviously have been an actual error of about 8·3 per cent. in the comparison between the two races due, not to racial characters, but to soil and other conditions external to the plant. In other words, the experiment would have been (as most variety trials in the past have been) a combined trial of soil fertility and race productivity, and it would have been impossible to disentangle the two. When, however, comparison was made of the weights grown on the 250 pairs of adjacent plots, it was found that the probable error of the average difference between all adjacent plots taken in pairs was reduced to less than half of 1 per cent. If, therefore,

250 plots of each of *two* races had been planted in alternating strips of plots across the field, it may be assumed that whatever was the difference in the total weight of grain of the two races, the probable error of this difference due to soil conditions would have been only about half of 1 per cent., and that if the actual difference amounted to 2 per cent., viz., four times the probable error, it might safely have been regarded as 'significant'.

It becomes a problem in statistical inference to estimate the number of comparisons necessary with plots of any specified area in order that the probable error under any fairly normal external conditions shall not exceed, say, 1 per cent., and also to find the best way of splitting up any available area into such plots.

It was consideration of the above results, and more especially the contribution by 'Student', which suggested to me a method of yield-testing for barley which after some early preliminary experiments I put into practice at Warminster in 1920 for field tests of two different races. It is known as the 'half-drill strip' method and is described in the following chapter.

CHAPTER XXVII

THE HALF-DRILL STRIP METHOD

THE first half-drill strip experiment for field trials of two different races of barley was carried out at Warminster in 1920 and the results of the comparisons recorded.

This method has many advantages for trials of races of cereals on the field scale because it dispenses with seeding and harvesting by hand. Moreover, each trial is a separate unit and can therefore be dealt with individually. It came into use when Rothamsted was still on the single plot system and it has been adopted by the Irish Department of Agriculture, by the National Institute of Agricultural Botany, and by various experimental stations in other countries.

In the design of trials adapted to agricultural experiments it is essential not only to know the mathematical theory of probability applicable to such experiments, but also to have a knowledge of the material under investigation. In fact, agricultural methods should be designed by the agriculturist who has practical knowledge of the subject.

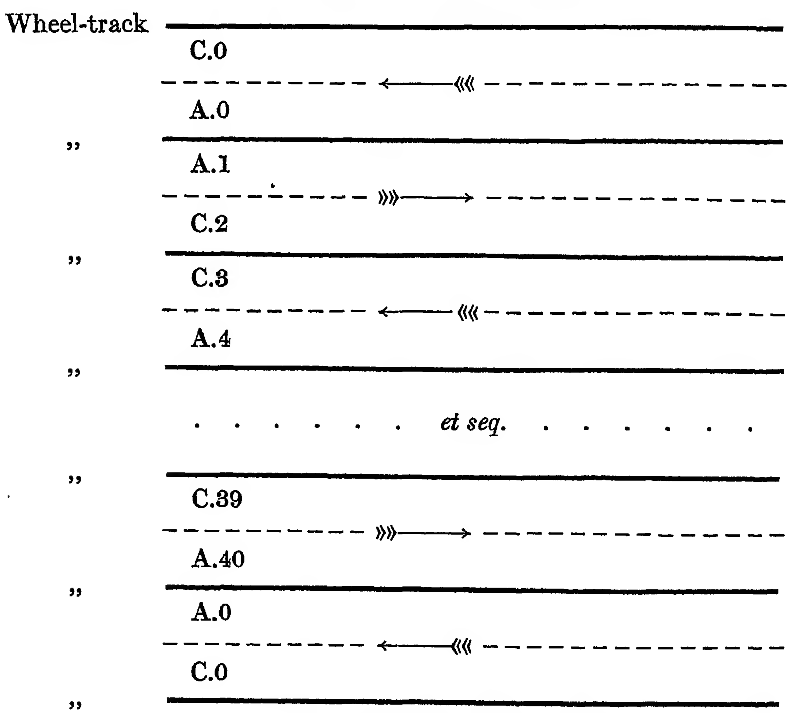
The half-drill strip method was designed to determine the comparative values of different races of barley: to minimize the effects of divergences external to the plant: and to combine the advantages of growing cereals on the large scale with an accuracy almost equal to that obtained in small-scale work. It is a method which is serviceable, economical of area, and above all practical. It requires careful supervision and accuracy of work, but the gain in yield per acre should more than compensate for the trouble expended and for the extra cost of labour involved.

Two races are compared on a total area of just over an acre in one year, with a standard deviation of less than 1 per cent. The new race under test is separately compared with an established standard race, or with a local race of the same cereal (or with both), called the 'Control'. The new race and the control race are each grown in ten, twelve, or more alternating strips of about one-twentieth acre per strip, as

shown in Fig. 38, where 'A' represents the new race and 'C' the control. These races are drilled simultaneously from two halves of the seed-drill, so as to produce a series of long narrow strips running across the field in the order A/C, C/A, A/C, C/A, etc. The scatter of the strips is designed to avoid bias due to soil heterogeneity. The series ends with a half-drill strip of the same race, thus balancing the linear term of the fertility slope.

The seed-box of the drill is divided into two, and in the case of a drill with an odd number of coulters, e.g. 13 or 15, the centre coulter is put out of action. One compartment of the seed-box is filled with seed of the new race and the other with seed of the control race.

Fig. 38.—Lay-out of Half-drill Strips



C. = control race. A. = new race.

After each turn of the drill, two half-drill strips of the same race will be seeded alongside, and when the drill has

made 21 'turns' there will be 10 drill-wide strips (20 half-drill strips) of each race and two half-drill strips, one at each end of the series. The produce of the two half-drill strips first drilled at the edge of the field is not included in the experiment, and therefore the weighed produce in this case will be that of 20 half-drill strips, or half an acre of each race. If the series consists of only one race and a 'control' it will be best to drill 22 strips and exclude one full drill strip (two half-drill strips) at each end of the series. The strips can be split lengthwise at harvest and each half-strip of one race can be compared with the half-strip of the other adjacent race.

When sowing, care should be taken that the coulters of the drill should be at precisely equal distances apart, except the two on either side of the centre, where, in the case of a drill with an odd number of coulters, one is put out of action. It is necessary, therefore, to use a drill in which the distances apart of the coulters are adjustable. It is convenient to have something more than a row-space along the lines separating the two races, i.e. in the centre of the drill, but it is imperative that the over-all width of the two half-drill strips should be precisely equal, so that each race gets an equal area. It is also very necessary that all the coulters should deliver the seed at equal depths. The two halves of the drill should in fact be alike in all respects.

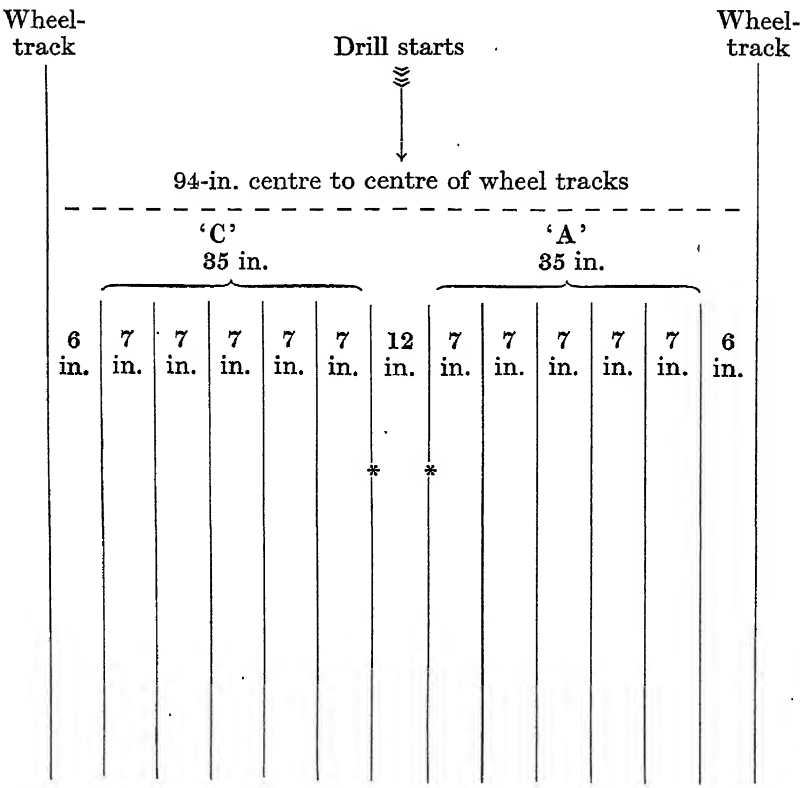
The drill should be fitted with a good steerage and the first 'turn' should be driven on a marked-out line. At each successive turn it should be so driven as to give a uniform space in the line of the wheel-tracks which will be the centre line of each racial strip, dividing each such strip into two equal half-drill strips. This space should be equal to that in the centre of the drill separating the two races. The effect will be to give each half-drill strip an equal area with something more than a row space in the centre of each racial strip, and a similar space between each racial strip: all the spaces being uniform in width. This arrangement is necessary in order to facilitate separation of the races at harvest.

The diagram on p. 278 shows that with a 13-coulter drill using 12 coulters 7 in. apart, and with 12-in. spaces between the half-drill strips, the width actually seeded, including spaces,

is 47 in. for each half-drill strip. The length required to give 1/40th acre per half-drill strip is therefore in this case 278 feet. If less or more coulters are used the length will be correspondingly altered.

FIG. 39.—Half-drill Strip Row Spacing.

13-Coulter Drill (12 Coulters working)



* Exclude before harvest.

The above is the length of the strips to be harvested. The length to be drilled should be about 9 ft. more, because it is not possible to start and stop the drill exactly on a line, and also the ends must be trimmed to a straight line across the strips before harvest. Obviously the precise areas seeded are not important provided they are equal and accurately

measured. The produce can then be corrected to yields per acre after harvesting.

Where the shape of the field is such that strips of twice the above length are more convenient, half the above number of strips of each race may be sown. In this case the length should be somewhat more than doubled and a space of about 10 feet cut out across the middle of the strips in order to make two sets of 10 half-drill strips of each race. The full length to be drilled, allowing for this space and for trimming the ends, will be about 580 feet in the case of a 13-coulter drill with 12 coulters working.

Where, as is frequently the case, it is found impossible to avoid placing the trial on land which has been differently cropped or manured in previous years, the strips should, if possible, cross the lines marking the different soil conditions rather than run parallel with them. If possible the longitudinal direction of the strips should be north and south, or as nearly so as the shape of the field admits.

It will be noted that one acre is required for each race when only one control is used, and two acres for each race when two controls are used, because in the case of two control races the experiment is duplicated in every respect by the addition of the second control race.

Drilling will be found to be much less complicated than would appear from the above directions. Once the drill has been adjusted this goes forward as rapidly as with ordinary drilling. It is quite possible to drill 6 or 8 acres, viz., 6 or 8 separate racial trials, in one day if the drill is prepared for use beforehand and if the superintendent is familiar with the method and has two or three intelligent helpers, one of whom must be an expert drillsman. A good deal of time is occupied in cleaning out the drill (or half the drill where the same control is used for several new races), but no more than when single half-acre plots of each race are drilled.

The method to be followed in cutting and in the subsequent operations will depend partly on the state of the crops at harvest time and partly on the degree of accuracy which is aimed at.

A source of systematic error is introduced in all strip methods of comparison if there is 'interference' of one race with another along the lines of separation. Interference will

often arise either from one race overtopping the other, or from 'lodging' across the strips; or from a more active root system of one race than of the other causing more vigorous growth of that race along each line of division.

It will generally be necessary to make sure of eliminating this possible systematic error. This can be done by cutting out before harvest one row of each race along the lines of separation. This will reduce the number of rows in each half-drill strip and involve either an addition to the length of the strips, or a correction of the figures to give yield per acre. The method of calculating the probable error of the experiment will not be affected. The additional labour will be fairly considerable, but the work can be done some time before harvest and will facilitate cutting and harvesting.

If the two races ripen so nearly together that they may be cut on the same day, and if there is not much 'lodging', the cutting can be done with a 'side-delivery reaper'. If the difference in time of ripening is only a few days the early-ripening race may be left standing till the later one is ready for cutting, and, in the case of barley, this will generally be possible. If, however, the difference is so great that there would be any risk of 'shattering' of the grain of the earlier race, the strips must be cut by hand: also, obviously, if there is severe lodging hand-cutting is the only feasible plan. If the lodging is across the plots it may be necessary to go down the spaces between the half-drill widths with a stave and throw back on either side the produce of each strip in order to make a clean separation immediately before cutting.

At Warminster, even in years when the straw was very heavy, we have had no difficulty in cutting the barley with a side-delivery reaper (Fig. 40). It may be more likely to be necessary to cut by hand in the case of oats than of either wheat or barley. In any case, whether the plots are cut by hand or by a reaper, it is imperative that the two races should be kept rigidly distinct.

In the 1920 and 1921 experiments at Warminster the half-drill strips of the two races under comparison were cut with a side-delivery reaper—each half-drill strip separately—and in order to leave approximately the same amount of stubble on all the plots, so that the straw-weights as well as the grain-

Fig. 40. Side-delivery reaper.

To face page 280

weights might be comparable, the strips were cut in only one direction.

It has been found in repeated experiments that the ratio of grain to straw is constant within very narrow limits for the same race when grown under the conditions described. It may therefore be safely assumed that the probable error of the total grain-weights of each race is not appreciably greater than that of the average total produce on a large number of small areas of each race.

From the tabulation of results of a very large number of similar cases I have found that the probable error of the weight of grain is, in fact, less than that of the corresponding weights of grain plus straw.

Results which have been obtained indicate that by the half-drill strip method the probable error of the difference between the weights of grain of the two races may be reduced to about one-half of 1 per cent., as against something over 5 per cent. when single plots are compared.

The results of the 1921 field trial at Warminster are shown in Tables XLII and XLIII. The weights of the sheaves on the individual half-drill strips are given, together with 243 of the 270 'plots' which go to make up the half-drill strips respectively.

The weights of the sheaves total up to 'C' (control) 4251·3 lbs., 'A' (new race) 4368·1 lbs., therefore if 'C' = 100, 'A' = 102·7. The total weight of the sheaves of 'C' and 'A' taken together on the west half-acre was 4049·7 lbs., and the total weight on the east half-acre was 4569·7 lbs. If, therefore, two single half-acre plots had been grown on this field, which from superficial examination appears to be of over-average uniformity, the difference of the total produce weighed in the field between the two races would have appeared to be something more than 13 per cent., but we should have been measuring soil fertility rather than inherited productivity.

'*Probable Error*'.—It will be seen from the tables and the appended notes that the probable error of the actual weights of total produce has been calculated in four different ways, viz., in two different ways from 27 half-drill strip weights of each race, and in two different ways from 243 'plot' (double-sheaf) weights of each race.

TABLE XLII.—Warminster Field Trial, 1921. Half-drill Strip Weights, comparing: Two races of barley, viz., 'C' and "A'. Area of each half-drill strip = 100 sq. yds. Total area = 2,700 sq. yds. = ·56 acre for each race. Showing total weight of sheaves on each half-drill strip.

Half-drill strip		Weight of sheaves on half-drill strip		Difference between 'A' & 'C'	Half-drill strip		Weight of sheaves on half-drill strip		Difference between 'A' & 'C'
No.		lbs.		lbs.	No.		lbs.		lbs.
'C'	'A'	'C'	'A'	'A' ± 'C'	'C'	'A'	'C'	'A'	'A' ± 'C'
1	2	165·4	164·6	− 0·8	29	30	160·9	160·2	− 0·7
4	3	159·5	173·4	+13·9	32	31	153·2	164·3	+11·1
5	6	169·3	169·3	..	33	34	144·9	154·3	+ 9·4
8	7	179·8	174·9	− 4·9	36	35	147·7	158·6	+10·9
9	10	172·5	177·6	+ 5·1	37	38	142·4	143·0	+ 0·6
12	11	170·7	182·9	+12·2	40	39	138·7	143·6	+ 4·9
13	14	173·3	167·5	− 5·8	41	42	131·1	143·2	+12·1
16	15	166·1	178·5	+12·4	44	43	141·6	145·3	+ 3·7
17	18	174·5	170·3	− 4·2	45	46	145·0	150·1	+ 5·1
20	19	163·3	176·0	+12·7	48	47	155·4	154·0	− 1·4
21	22	166·0	159·1	− 6·9	49	50	151·1	149·3	− 1·8
24	23	161·2	168·7	+ 7·5	52	51	145·6	149·7	+ 4·1
25	26	169·3	164·2	− 5·1	53	54	146·3	158·5	+12·2
28	27	156·5	167·0	+10·5		Total	4251·3	4368·1	..
					Average		157·5	161·8	+ 4·3
					Per cent.		100	102·7	+ 2·7

Note on Table XLII.—The Standard Deviations of the half-drill strip weights computed in the usual manner are:

'C'—12·65 lbs. per half-drill strip = 8·03 per cent.
'A'—11·60 lbs. per half-drill strip = 7·80 per cent.

The Probable Error of the difference between the *two averages* (viz., 157·5 lbs. and 161·8 lbs.) is ± 2·2 lbs. and the probable error of the differences between

TABLE XLIII.—Showing Weights of each 'Plot' (two consecutive sheaves), 9 plots (=18 sheaves) on each half-drill strip. Total number of plots on 27 half-drill strips = 27 by 9 = 243 plots of each race (excluding end sheaves which are left out of account in this case in computing 'probable error').

Nos. of half-drill strips 'C' 'A'	'Plot' weights 2 sheaves lbs. 'C'	'A'	'A' ± 'C' lbs.	Nos. of half-drill strips 'A' 'C'	'Plot' weights 2 sheaves lbs. 'A'	'C'	'A' ± 'C' lbs.
1 2	17·0	17·6	+ 0·6	3 4	17·4	16·3	+ 1·1
	15·8	16·9	+ 1·1		16·6	16·0	+ 0·6
	14·2	15·0	+ 0·8		16·5	16·1	+ 0·4
	14·2	13·8	− 0·4		15·4	13·2	+ 2·2
	16·2	15·8	− 0·4		15·6	13·7	+ 1·9
	17·3	17·0	− 0·3		18·9	16·7	+ 2·2
	18·0	17·1	− 0·9		18·6	15·6	+ 3·0
	17·8	17·2	− 0·6		17·8	16·9	+ 0·9
	16·6	17·8	+ 1·2		18·6	17·3	+ 1·3
	147·1	148·2			155·4	141·8	
	18·3*	16·4*			18·0*	17·7*	
	165·4	164·6	− 0·8		173·4	159·5	+13·9
5 6	16·4	16·2	− 0·2	7 8	18·1	17·9	+ 0·2
	17·7	16·8	− 0·9		16·8	17·1	− 0·3
	13·0	14·8	+ 1·8		14·8	15·3	− 0·5
	14·5	14·4	− 0·1		16·0	15·9	+ 0·1
	15·2	15·8	+ 0·6		16·3	16·6	− 0·3
	17·7	17·3	− 0·4		17·0	18·3	− 1·3
	18·7	17·9	− 0·8		18·5	19·7	− 1·2
	17·7	16·5	− 1·2		17·9	18·6	− 0·7
	19·1	18·9	− 0·2		19·3	19·7	− 0·4
	150·0	148·6			154·7	159·1	
	19·3*	20·7*			20·2*	20·7*	
	169·3	169·3			174·9	179·8	− 4·9
9 10	17·6	16·7	− 0·9	11 12	18·0	16·1	+ 1·9
	17·2	16·9	− 0·3		16·1	15·6	+ 0·5
	16·0	15·8	− 0·2		15·9	14·2	+ 1·7
	17·0	15·9	− 1·1		16·9	15·6	+ 1·3
	17·3	17·4	+ 0·1		18·1	16·5	+ 1·6
	16·0	17·2	+ 1·2		17·6	15·7	+ 1·9
	20·1	19·0	− 1·1		19·4	18·5	+ 0·9
	18·6	18·5	− 0·1		18·2	17·9	+ 0·3
	20·5	19·0	− 1·5		19·2	19·9	− 0·7
	160·3	156·4			159·4	150·0	
	12·2*	21·2*			23·5*	20·7*	
	172·5	177·6	+ 5·1		182·9	170·7	+12·2

the 'total produce' weights of 'C' and 'A' is $(2{\cdot}2 \times \sqrt{2})$ lbs.) = ±1·41 *per cent.* of the total weight of 'C'. Therefore: If 'C' = 100, 'A' = 102·7 ± 1·41.

By 'Student's' method, the Standard Deviation of the *differences between adjoining* half-drill strip weights is 6·7 lbs. per half-drill strip = 4·25 per cent. The Probable Error of the *average difference* (viz., + 4·3 lbs.) between adjoining half-drill strips is ±·87 lb., and the probable error of the difference between the 'total produce' weights of 'C' and 'A' is +·55 *per cent.* of the total weight of 'C'. Therefore: If 'C' = 100, 'A' = 102·7 ± ·55.

TABLE XLIII—*continued*

Nos. of half-drill strips 'C' 'A'	'Plot' weights 2 sheaves lbs. 'C'	'A'	'A' ± 'C' lbs.	Nos. of half-drill strips 'A' 'C'	'Plot' weights 2 sheaves lbs. 'A'	'C'	'A' ± 'C' lbs.
13 14	16·4	15·7	− 0·7	15 16	18·5	16·4	+ 2·1
	16·5	17·1	+ 0·6		15·9	16·1	− 0·2
	14·4	13·7	− 0·7		15·9	16·0	− 0·1
	14·4	15·0	+ 0·6		16·0	16·0	..
	17·2	15·8	− 1·4		15·6	16·1	− 0·5
	16·5	17·3	+ 0·8		17·4	16·1	+ 1·3
	19·6	16·8	− 2·8		19·6	16·7	+ 2·9
	18·5	18·6	+ 0·1		20·3	17·4	+ 2·9
	21·8	17·3	− 4·5		20·1	17·1	+ 3·0
	155·3	147·3			159·3	147·9	
	18·0*	20·2*			19·2*	18·2*	
	173·3	167·5	− 5·8		178·5	166·1	+12·4
17 18	18·1	17·1	− 1·0	19 20	16·2	15·7	+ 0·5
	16·6	17·6	+ 1·0		17·7	15·2	+ 2·5
	17·1	16·1	− 1·0		16·8	15·4	+ 1·4
	16·8	16·4	− 0·4		16·6	14·1	+ 2·5
	15·8	14·6	− 1·2		16·8	14·6	+ 2·2
	16·0	15·3	− 0·7		16·4	17·3	− 0·9
	18·1	18·1	..		19·1	17·7	+ 1·4
	17·3	18·0	+ 0·7		18·0	16·3	+ 1·7
	18·5	17·3	− 1·2		19·1	16·4	+ 2·7
	154·3	150·5			156·7	142·7	
	20·2*	19·8*			19·8*	20·6*	
	174·5	170·3	− 4·2		176·0	163·3	+12·7
21 22	16·3	15·9	− 0·4	23 24	14·4	15·2	− 0·8
	16·5	14·6	− 1·9		16·5	14·7	+ 1·8
	16·4	13·6	− 2·8		15·3	16·2	− 0·9
	14·7	14·0	− 0·7		14·6	14·2	+ 0·4
	13·3	13·5	+ 0·2		14·3	14·6	− 0·3
	17·1	15·4	− 1·7		16·9	15·3	+ 1·6
	18·2	18·1	− 0·1		18·7	17·3	+ 1·4
	16·8	17·2	+ 0·4		18·2	16·6	+ 1·6
	16·9	16·7	− 0·2		18·7	17·0	+ 1·7
	146·2	139·0			147·6	141·1	
	19·8*	20·1*			21·1*	20·1*	
	166·0	159·1	− 6·9		168·7	161·2	+ 7·5
25 26	15·5	14·1	− 1·4	27 28	14·7	14·6	+ 0·1
	13·7	16·7	+ 3·0		15·6	15·3	+ 0·3
	16·0	14·5	− 1·5		14·8	15·3	− 0·5
	14·1	15·7	+ 1·6		14·2	13·7	+ 0·5
	16·6	16·9	+ 0·3		15·4	15·8	− 0·4
	17·2	15·2	− 2·0		18·8	15·8	+ 3·0
	19·4	18·3	− 1·1		18·3	17·0	+ 1·3
	18·0	17·1	− 0·9		19·2	15·7	+ 3·5
	18·6	16·8	− 1·8		17·5	16·6	+ 0·9
	149·1	145·3			148·5	139·8	
	20·2*	18·9*			18·5*	16·7*	
	169·3	164·2	− 5·1		167·0	156·5	+10·5

TABLE XLIII—*continued*

Nos. of half-drill strips 'C' 'A'	'Plot' weights 2 sheaves lbs. 'C'	'A'	'A' ± 'C' lbs.	Nos. of half-drill strips 'A' 'C'	'Plot' weights 2 sheaves lbs. 'A'	'C'	'A' ± 'C' lbs.
29 30	14·7	14·0	− 0·7	31 32	14·2	13·5	+ 0·7
	14·2	13·6	− 0·6		15·3	13·6	+ 1·7
	14·8	14·5	− 0·3		14·4	13·5	+ 0·9
	15·7	14·8	− 0·9		13·3	12·0	+ 1·3
	16·9	15·9	− 1·0		17·1	17·3	− 0·2
	16·4	16·5	+ 0·1		16·8	14·7	+ 2·1
	17·0	16·8	− 0·2		18·9	17·3	+ 1·6
	16·7	18·0	+ 1·3		19·0	15·9	+ 3·1
	16·5	17·5	+ 1·0		17·2	17·8	− 0·6
	142·9	141·6			146·2	135·6	
	18·0*	18·6*			18·1*	17·6*	
	160·9	160·2	− 0·7		164·3	153·2	+11·1
33 34	13·5	14·8	+ 1·3	35 36	15·0	13·1	+ 1·9
	10·7	12·5	+ 1·8		13·7	11·3	+ 2·4
	12·8	12·7	− 0·1		12·6	13·5	− 0·9
	12·6	14·0	+ 1·4		14·3	14·5	− 0·2
	15·3	16·3	+ 1·0		16·4	16·8	− 0·4
	15·3	15·9	+ 0·6		17·4	12·6	+ 4·8
	17·5	18·1	+ 0·6		15·3	17·4	− 2·1
	15·9	17·5	+ 1·6		16·1	14·6	+ 1·5
	14·8	15·1	+ 0·3		17·9	16·3	+ 1·6
	128·4	136·9			138·7	130·1	
	16·5*	17·4*			19·9*	17·6*	
	144·9	154·3	+ 9·4		158·6	147·7	+10·9
37 38	12·6	11·4	− 1·2	39 40	11·8	11·4	+ 0·4
	11·4	12·9	+ 1·5		11·9	11·1	+ 0·8
	11·9	11·9	..		12·3	12·9	− 0·6
	15·4	14·3	− 1·1		12·8	13·6	− 0·8
	15·1	16·7	+ 1·6		16·6	13·1	+ 3·5
	14·0	15·8	+ 1·8		14·2	15·3	− 1·1
	15·1	13·8	− 1·3		16·8	16·0	+ 0·8
	13·8	14·7	+ 0·9		15·3	14·7	+ 0·6
	16·0	14·7	− 1·3		16·2	13·8	+ 2·4
	125·3	126·2			127·9	121·9	
	17·1*	16·8*			15·7*	16·8*	
	142·4	143·0	+ 0·6		143·6	138·7	+ 4·9
41 42	10·6	11·4	+ 0·8	43 44	11·1	11·8	− 0·7
	9·7	11·1	+ 1·4		10·9	12·0	− 1·1
	11·4	10·1	− 1·3		12·3	11·0	+ 1·3
	11·9	10·7	− 1·2		12·0	13·6	− 1·6
	12·9	13·3	+ 0·4		14·4	15·6	− 1·2
	13·8	15·9	+ 2·1		15·5	15·0	+ 0·5
	16·5	19·5	+ 3·0		17·3	16·2	+ 1·1
	14·4	16·6	+ 2·2		15·7	15·8	− 0·1
	14·1	16·2	+ 2·1		18·3	14·3	+ 4·0
	115·3	124·8			127·5	125·3	
	15·8*	18·4*			17·8*	16·8*	
	131·1	143·2	+12·1		145·3	141·6	+ 3·7

TABLE XLIII—*continued*

Nos. of half-drill strips 'C' 'A'	'Plot' weights 2 sheaves lbs. 'C'	'A'	'A' ± 'C' lbs.	Nos. of half-drill strips 'A' 'C'	'Plot' weights 2 sheaves lbs. 'A'	'C'	'A' ± 'C' lbs.
45 46	11·6	13·2	+ 1·6	47 48	11·8	12·9	− 1·1
	11·7	12·5	+ 0·8		13·0	13·4	− 0·4
	10·7	12·2	+ 1·5		13·9	13·9	..
	13·9	14·5	+ 0·6		16·7	14·9	+ 1·8
	15·8	15·6	− 0·2		15·6	16·3	− 0·7
	14·8	16·2	+ 1·4		16·4	17·0	− 0·6
	16·8	16·1	− 0·7		15·6	17·0	− 1·4
	17·4	16·0	− 1·4		17·6	15·7	+ 1·9
	16·8	16·2	− 0·6		16·3	17·1	− 0·8
	129·5	132·5			136·9	138·2	
	15·5*	17·6*			17·1*	17·2*	
	145·0	150·1	+ 5·1		154·0	155·4	− 1·4
49 50	13·6	13·8	+ 0·2	51 52	14·2	13·5	+ 0·7
	12·5	13·0	+ 0·5		12·8	11·5	+ 1·3
	13·6	13·8	+ 0·2		14·3	13·7	+ 0·6
	14·5	13·0	− 1·5		13·5	14·2	− 0·7
	15·3	13·9	− 1·4		14·3	14·1	+ 0·2
	15·9	15·6	− 0·3		15·3	14·1	+ 1·2
	16·6	15·6	− 1·0		14·5	16·0	− 1·5
	16·8	17·1	+ 0·3		16·7	15·7	+ 1·0
	16·4	16·0	− 0·4		16·4	15·6	+ 0·8
	135·2	131·8			132·0	128·4	
	15·9*	17·5*			17·7*	17·2*	
	151·1	149·3	− 1·8		149·7	145·6	+ 4·1
53 54	13·8	13·1	− 0·7				
	12·3	12·2	− 0·1				
	11·8	14·8	+ 3·0	Average weight per 'plot' (end sheaves excluded)	'C'	'A'	'A' ± 'C'
	13·9	13·6	− 0·3				
	16·2	15·6	− 0·6				
	15·1	16·5	+ 1·4				
	15·5	16·0	+ 0·5		15·56	15·88	+ 0·32
	15·4	19·0	+ 3·6				
	17·2	16·5	− 0·7	per cent.	100·0	102·1	+ 2·10
	131·2	137·3					
	15·1*	21·2*					
	146·3	158·5	+12·2				

* These figures represent weights of the first and last sheaves on each half-drill strip added together, and are excluded in calculating the average weights and also in calculating the 'probable error'.

The two different ways are:

(*a*) The probable error of the average of the "C' strips (or plots) is calculated, and also the probable error of the average of the 'A' strips (or plots), and from these figures the probable error of the difference of these two averages is obtained. This is the usual way of calculating the difference of two averages.

(*b*) The difference in the weights of pairs of adjoining strips (or plots), i.e., 'A' ± 'C' compared in the order of C, A; A, C; C, A; A, C; *et seq.*, is set down and the probable error of the average difference is calculated. This is the method suggested by 'Student' in the paper by Hall and Mercer (1911) already referred to.

It will be observed that by this method an 'A' plot is compared alternately with a 'C' plot on the right and on the left. The effect of this is to discount any 'fertility slope' of the field.

The following are the probable errors so obtained:

1. From half-drill strip weights—
   (*a*) Usual method ±1·41 per cent.
   (*b*) 'Student's' method ±0·55 per cent.
2. From 'plot' (double-sheaf) weights—
   (*a*) Usual method ±0·81 per cent.
   (*b*) 'Student's' method ±0·37 per cent.

The well-marked reduction of the probable error by 'Student's' method is largely due to the fact that in this particular field the fertility declines, although not uniformly, from east to west.

Note on Table XLIII.—The Standard Deviations of the above 'plot' (double sheaf) weights computed in the usual manner are:

'C'—2·08 lbs. per plot = 13·1 per cent.
'A'—2·09 lbs. per plot = 13·4 ,,

The probable error of the difference between the two average plot weights (viz., 15·56 lbs. and 15·88 lbs.) is ·126 lb. and the probable error of the difference between the 'total produce' weights of 'C' and 'A' is ·81 *per cent.* of the total weight of 'C'. Therefore: If 'C' = 100, 'A' = 102·1 ± ·81.

By 'Student's' method, the standard deviations of the *differences in* adjoining 'plot' weights is 1·35 lbs. per plot = 8·6 per cent.

The probable error of the *average difference* between *adjoining plots* (viz., ·32 lb.) is ·0575 lb., and the probable error of the difference between the 'total produce' weights of 'C' and 'A' is ·37 *per cent.* of the total weight of 'C'. Therefore: If 'C' = 100, 'A' = 102·1 ± ·37.

At another station where the divergencies were more irregular in character there might be less difference in the probable errors obtained by the two methods. It appears, however, to be clear that the second method gives the probable error more correctly and it is no more difficult to calculate.

It might perhaps be concluded that a sufficiently near estimate of the probable error is obtained from weighing the total produce of, say, 10 or 12 strips of each race. Although this might be so with fields as uniform as in this case; it would not be so with less uniform fields, and, moreover, there is very little extra labour involved in splitting the drill-widths first longitudinally into half-drill strips, and then into plots if the latter operation can be performed by using either a side-delivery reaper or a binder suitably adjusted, and then weighing the sheaves. If, however, the strips have to be cut by hand, and time or supervision is too limited to permit of splitting the strips into plots, the sheaf-weights of the half-drill strips are better than nothing.

In any case, when results are published the method by which the strips were cut and the probable error calculated should be stated.

Weights of Threshed Grain and Straw in 1921.—The produce of the 'C' and 'A' 'half-drill strips' in 1921 was separately harvested one week after the above weighings were made and threshed immediately. The following figures show that there was in the meantime a loss of weight of about 4 per cent. in the case of 'C' and about 5 per cent. in the case of 'A'. From moisture determinations on samples of grain and straw taken (1) at time of field weighing, and (2) at time of threshing, it appeared that this was due to the grain having lost about 2 per cent. and the straw about 6·5 per cent. of water. It may be noted that in some seasons the drying of the crop in the field would give a much greater difference than this—depending of course on the weather.

	'C' lbs.	'A' lbs.	Grain per cent. of total produce
Grain as threshed—			
containing 13·8 per cent. water .	1,820	..	44·5
„ 13·8 „ „ .	..	1,871 (100 : 102·8)	44·9
Straw, etc., as threshed—			
containing 17·4 per cent. water .	2,269		
„ 16·9 „ „ .	..	2,287 (100 : 100·8)	
Total Produce as threshed . .	4,089	4,158 * (100 : 101·7)	
loss of weight— 'C' 3·8 per cent. 'A' 4·8 „ . .	162·3	210·1	
Field Weights from Table XLII .	4,251·3	4,368·1 (100 : 102·7)	

Dry Weights.—The dry weights of grain, straw and total produce calculated from the above figures are:

	·56 acre 'C' lbs.		·56 acre 'A' lbs.	Grain per cent. of total produce
Grain . .	1,565			45·4
„ . .		(100 : 103·0)	1,613	45·9
Straw . .	1,877			
„ . .		(100 : 101·3)	1,901	
Total .	3,442	(100 : 102·1)	3,514	

From the above it appears to be certain that the probable error of the difference in the grain weights is less than $\pm\cdot5$ per cent. and that the difference of 3·0 per cent. (equal to

* In terms of 'yield per acre' of raw produce:

	'C' (lbs.)	'A' (lbs.)
Grain .	3,249 = 58·0 bush. (of 56 lbs.)	3,339 = 59·6 bush. (of 56 lbs.)
Straw .	4,050 = 36·2 cwts.	4,085 = 36·4 cwts.
	7,299	7,424

about $1\frac{1}{2}$ bush. per acre) in favour of the weight of grain on 'A' is a significant difference, not due to chance conditions. A similar difference between two single half-acres would have been devoid of any significance.

It was discovered that there was a systematic error in this particular (1921) experiment due to an alternating systematic difference in the spaces separating the two adjoining strips of the same race. This was apparently caused by one horse in the drill pulling harder than the other, with the effect that when the drill was travelling from north to south the spaces between the two half-drill widths of the same race were slightly wider than when the drill travelled in the opposite direction. The result was to give to the strips of one race a slightly larger area than to the other.[1]

In 1923, when Gosset ('Student') was present at the harvesting of the crop, he pointed out that since the *sheaf-weights* may be positively correlated, the method of weighing the sheaves would be likely to give a fallaciously small value, and since that time the whole length of the strip has been taken as the unit in the calculation. Also, to avoid any further source of error we adopted a 16-coulter drill, discarding two rows on each side of the wheel-tracks, to avoid any possibility of inaccuracy due to uneven spacing; and four rows, viz., 7·8/9·10 and 10·9/8·7, to avoid 'interference' of one race with another in an adjoining strip. Spaces of nine inches were left between rows 2/3, 6/7, 10/11 and 14/15 to facilitate harvesting the crop with a horse-drawn reaping machine, cutting each four rows separately. Ten complete strokes of the drill, each about 100 yards long, are drilled and at harvest the ends are discarded. Fig. 41 shows the arrangement adopted.

It still obviously remains necessary to make sure that the coulters of the drill are so set as to give precisely equal areas to each race, or, failing that, to measure accurately the widths of the strips after harvest. It is a fairly easy matter to measure the total width from the outside drill of one half-drill strip to the outside drill of the same race. This measurement includes the space between the drill strips, which is

[1] Measurements which were made on the stubble of the 1923 experiment showed that not only did such inaccuracies occur, but also that they can favour one or other of the races.

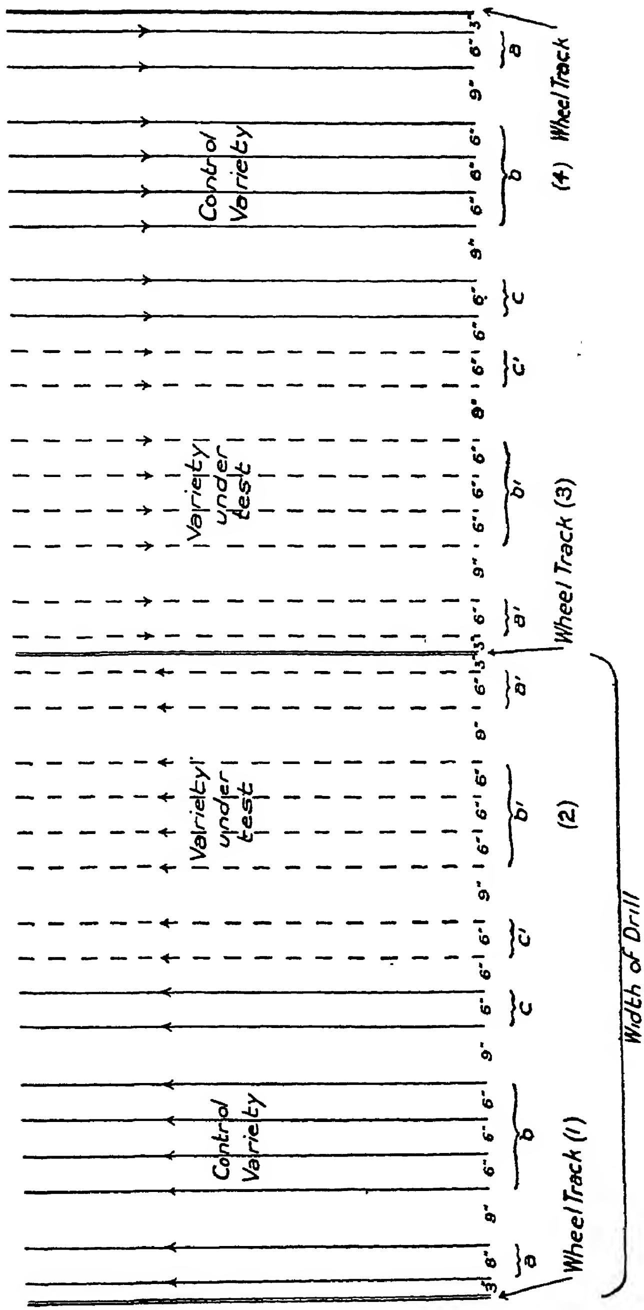


FIG. 41. Row-spacing using 16-coulter drill.

To face page 290

variable owing to the difficulty of steering, and is now made in practice across each drill strip in several places. It is thus possible to estimate with accuracy the total area occupied by each race and to make the necessary correction to the total yields.

In 1938 there were three half-drill strip experiments of four races: 35/51S. against 54/12; Plumage-Archer 1935 against 54/12/3; arranged in the form *abba cddc abba*, etc.; and finally, 54/12 against 54/13. Fig. 42 shows discards of 2 rows for each race; Fig. 43 shows lines of sheaves transversely to line of strips, and Fig. 44 shows lines of sheaves diagonally to line of strips.

In 1939 there were similar experiments, but discards were reduced to one row instead of two rows, so there were 6 drills per half-strip harvested and weighed instead of 4 drills. This ensured a saving of space—three-fourths (12/16ths) of the entire area being utilized instead of one-half. There were 16 half-drill strips of each race 264 feet long: the area of each race harvested being approximately ·314 acre.

The Half-drill Strip Method and 'Artificial Randomization'

The half-drill strip method, which is a balanced arrangement, has of late years been adversely criticized by some who prefer 'artificial randomization', and in a paper read to the Agricultural and Industrial Section of the Royal Statistical Society (1936) 'Student' made the following comment:

'It has been said that from an experiment conducted by this method no valid conclusion can be drawn, but even if this were so it would not affect a *series* of such experiments. Each is independent of all the others and it is not necessary to randomize a series which is already random, for as Lincoln said—"You can't unscramble an egg." Hence, since the tendency of deliberate randomizing is to increase the error, a balanced arrangement like the half-drill strip is best if otherwise convenient.'

In the same year there appeared in the *Annals of Eugenics* a paper entitled 'A Test of the Supposed Precision of Systematic Arrangements' by Barbacki and Fisher (1936), written with the intention of testing the differences of

opinion between the authors and 'Student' (as set out in the above paper).

Barbacki and Fisher in order to accomplish their purpose assigned the crop on a uniformly treated field to two imagined treatments, A and B, on a systematic plan, in which 8 strips of the width of a half-drill were allotted to A and 8 to B, in the usual arrangement of an eight-comparison half-drill strip experiment.

[I would remark, by the way, that there should be at least ten comparisons, and in my original (1921) experiment there were twenty-six.]

The paper was critically dealt with by 'Student' in a letter to *Nature* (1936), in which he says *inter alia*:

'The authors, for the purpose of ascertaining the degree of precision which is obtainable from the systematic arrangement in question, have taken the weights of grain, not from the total area of the 16 strips, but from 12 sections of each strip, and have treated these 192 sections as if they were independent half-drill strips—in fact they have called them half-drill strips—and from the 96 comparisons they have calculated a standard error to represent the precision which they suppose an advocate of systematic arrangements would attribute to the method. But, of course, the sections of a half-drill strip are not in fact independent, and in this case are markedly correlated, so that the figure which they obtain is much too small to account for the observed difference between the A's and the B's—and they draw conclusions adverse to the systematic arrangement and not to their own method of calculation.'

'Student' concludes his letter thus: 'Their paper has no bearing whatever on the error of present-day half-drill strip experiments.'

Later, in a posthumously published paper (which appeared in *Biometrika* (1938)) entitled 'Comparison between Balanced and Random Arrangements of Field Plots', 'Student' sets out his arguments very fully, with data to illustrate his points. He shows that the conclusions arrived at by Professor Fisher all follow from the fact that, firstly, he has calculated the error of the systematic (balanced) arrangements by a method originally adopted at Warminster, but not put into

FIG. 42.—Discards at harvesting half-drill strips.

To face page 292

use after 1923; and, secondly, that he has not compared like with like.

Finally, to emphasize what I have already indicated with reference to balanced arrangements for the conduct of field trials of cereals, all that is needed in my opinion is absence of bias, with plentiful replications. The greater the number of replications at all sorts of times and places the less chance there is of bias. It is admitted that it is difficult in field trials of races to avoid bias completely, whatever the lay-out adopted may be. The important thing is to secure such a method and to get sufficient independent examples to reduce the probable error, the extent of which will always depend on the numbers involved.

The experimental error obtained by the half-drill strip method is as low as can be obtained by any existing method, provided the same degree of intelligence is used as is requisite for other experimental work, and any method which reduces the error of experiment is worthy of notice.

If the error of experiment is not reduced below a certain point, either by replication or by intelligent lay-out, then the conclusions cannot be valid and the whole experiment is useless.

I would stress the point that the object of all agricultural plot experiments is to discover or establish some difference in treatment, or (as in variety tests) some difference in plant response to soil conditions, which may add to the value of the crop. Many of the 'randomized' plot arrangements appear to be designed mainly to illustrate statistical theory and certainly only a trifling number of them so far have demonstrated any fact of value to the farmer.

I am quite aware of the limitations of the half-drill strip method and would welcome any method which would be serviceable to our agricultural friends and at the same time reduce the extent of time required to select new races, which is at present about ten years. At the same time I think it may be admitted that the half-drill strip method has been of exceptional economic value to farmers. The greatest advantage of this method lies in the fact that it is comparable with ordinary farming practice, and that the use of drills, reaping machines, horses or tractors is fairly simple, whereas

with some other designs, e.g., Latin Squares, the use of these presents difficulties.

> *In the field, grain seeds are sown with very irregular spacing, and different races vary both in tillering power to fill up empty spaces and also in their reaction to overcrowding, and unless the Latin Square method can be used with irregular spacing, however conclusive the results are in themselves, they cannot possibly be applied to general agriculture without definite proof that spacing at regular intervals with cereals gives the same comparable results as with irregular. Such a proof appears never to have been made, despite the obvious necessity for it, as on theoretical grounds the probability is strongly against it.*

FIG. 43.—Lines of sheaves lying transversely to half-drill strips.

FIG. 44.—Half-drill strips viewed diagonally.

To face page 294

CHAPTER XXVIII

SELECTED TWO-ROWED HYBRID RACES OF BARLEY RAISED AT WARMINSTER

THE progeny of sixty-eight hybrids have been under observation from 1905 to 1938. A small number of these failed at time of crossing. Sixty cross-fertilization cultures were carried on to the F.3 generation, and a number of them for many more years. The entire produce of fifty-six of these was 'scrapped' at various stages as being of no particular value.

The following are some of the crosses from which selections were made (or are in process of being made):

Year of Cross

×14. 1905. Beaven's 'Plumage' (343) × Beaven's 'English Archer' (4).

The progeny of a selected F.2 plant (145) of this cross was distributed as 'Plumage-Archer 1914' in that year.

From the progeny of a number of single plants of '145', '145/46' was selected and distributed as 'Plumage-Archer 1924' in that year.

×35. 1923. Plumage-Archer 25/1 × Spratt-Archer 37/6.

The progeny of a number of F.2 plants with ears of type var. *nutans* was carried on to the F.3 generation and distributed as 'Golden-Archer' in 1932. This was a mass selection.

The progeny of a selected plant (35/7) with ears of type var. *erectum* of above cross was distributed in 1935 as 'Plumage-Archer 1935'.

'35/51S. is the progeny of a single plant selected from the progeny of one F.2 plant (35/51). It was distributed in 1938 as a new selected 'Golden-Archer'.

Year of Cross

×54. 1931. Plumage-Archer 1924 × Spratt-Archer 37, No. 3.

Each culture of ×54 is the progeny of one F.3 plant of above cross.

'54/12/3' is the progeny of a single F.3 plant of above cross.

×68. 1938. Plumage-Archer 1935 × Spratt-Archer 37, No. 3.

History and Description of Two-rowed Hybrid Races raised at Warminster

PLUMAGE-ARCHER (145)

This is a 'selected hybrid' race, resulting from the cross-fertilization of the two former 'pure races' Plumage (343) and English Archer (4).

History

×14

1905. F.0. Plumage (343) × Archer (4).

1906. F.1. Five grains from the above cross were planted, producing 5 plants bearing 24 ears, narrow, with medium neck.

1907. F.2. Twelve grains (one row) were planted from each of the above 24 ears. 218 plants matured, all 'splitting'. The ears from each of these plants were separately harvested and determinations made on width of ears, length of necks, number of ears per plant, nitrogen in average grain of each plant (i.e. in equal number of grains from centre of each ear), weight per 1,000 corns [of those grains on which nitrogen had been determined].

1908. F.3. 218 rows of 12 plants each were seeded—each from one ear of the above 218 plants. In August the produce of 2,168 plants was separately harvested. Width of ear and length of neck were noted for each plant and the material submitted to laboratory examination with a view to selection for 1909 planting. (Owing to excessive soil space for multiplication all the 1908 produce had very high nitrogen content.) In the same

year (1908) from the produce of the 218 plants of the 1907 (F.2) plots, 78 selected and apparently homozygous individuals were nursery-grown for multiplication with 1 sq. ft. soil space per plant. At harvest, not all appeared to be homozygous in structural characters, but 21 homozygous plants were selected for low average nitrogen content and high yield.

×14

1909. F.4. One row was planted from one selected ear of each plant grown in 1908. The 21 homozygotes were tested on the nursery-yield estimation system for yield and quality, and field plots of the same were grown for multiplication.

After keeping the progeny of each generation distinct, we had in this year over 2,000 'single plant cultures'. Many of these were, as in all similar cases, inconstant forms. The produce was sent to the School of Agriculture, Cambridge, with the exception of certain selected F.4's kept for multiplication.

1910. F.5. The whole of the progeny resulting from this cross was weighed up at Cambridge by my assistant, Mr. Wickham, under the supervision of Professor T. B. Wood and Mr. A. R. Bruce. For each plant the number of ears and the weight of straw and ears were recorded, from which factors the migration coefficient for each plant was calculated. After rejecting the cultures which were visibly heterogeneous in some character of the plant, the nitrogen content on half the grains of a large number of individual plants was determined.

In the same year chequer-board and field cultures were conducted at Warminster.

1911/13. F.6/7/8. Chequer-board and field cultures at Warminster. From the chequer-board cultures of 1911 and 1912 eight races were selected, each the progeny of a single F.2 plant, and the one which gave the best result in 1913 (after three years of cultivation on the field scale) was selected, viz., '145', as possessing good combinations of the desired characters of the two parent forms and became the parent culture of the Plumage-Archer stock.

The experimental cultures at Warminster, together with the results of the field crops of 1913 at Cambridge and Norfolk, showed that '145' gave an unusually high ratio of grain to straw (M): in some cases the yield of grain was 10 per cent. higher than that of other races with which it was compared and which gave the same weight of grain and straw taken together.

×14

1914. F.9. Distributed by the British Seed Corn Trade Association as 'Plumage-Archer 1914'.

It is interesting to note that from the cultures of this cross, one which appeared to be the worst was selected, viz., '135/6', and has been included in the chequer-board cultures at Warminster for purposes of comparison amongst the eight races planted in each successive year up to and including 1926. It is the progeny of the 6th out of 12 plants of No. 135 of the F.2 generation. It consistently gave the lowest yield and lowest ratio of grain to straw of any of the Plumage-Archer races raised at Warminster. It serves to illustrate the widely different character of progeny obtained by cross-fertilization of the same two plants. Its low-yielding character is probably due to feeble straw and consequent deficient 'migration'.

Description

The straw is erect, probably more so than that of any race in general cultivation up to the time of its distribution. In this respect it appeared to be a distinct improvement on both the parent races. The neck is short, like that of Archer, and not liable to 'kink'. The shape of the ear is wide like Plumage, but less brittle. The grain resembles that of Archer, but is superior in colour and size and also in respect of malting quality.

The length of the leaf-sheath from node to ligule is about the same (9 to 10 inches) in Archer, Plumage, and all the ×14's. I think, however, this varies greatly with the season and conditions generally. This sheath acts as a protective envelope to the stem and prevents bending and breaking, which always takes place either at the node or above the top of the leaf-sheath (ligule).

The yield, judged from a large number of experiments made in 1911, 1912 and 1913, was better than that of Plumage

and about equal to that of English Archer on good soils. There is a slight variation in length of straw (such as frequently occurs in hybrid races), but this in itself is not a serious defect and is associated with some difference in the size and quality of the grain of individual plants.

This race is specially suitable for soils in high condition, where good standing is essential to high yields and economical harvesting.

'PLUMAGE-ARCHER 1924' (145/46/55)

This is an 'extracted pure line'—the progeny of a 'selected single plant' of 'Plumage-Archer 1914' (145). It was selected both for good yield and good quality after exhaustive comparative trials between 1914 and 1924.

History

× 14/145

1910. A number of single plants of × 14/145 were selected from a field plot.

1911. From the progeny of these plants a chequer-board yield experiment was carried out with '145' as control.

1912. 46 plants of '145' were selected for stiff straw, short necks and high ratio of grain to straw (M). The families grown up from these plants were separately harvested and the migration factor for each determined. In all the characters significant differences were observed. Several of these sub-races were selected and the rest discarded.

1913. '145/46' was finally selected as being the most uniform in appearance of all the sub-races of '145' then growing in the nursery. It was then re-selected, this time for a character found to be systematically variable within the sub-race, viz., ratio of grain to straw.

1914. Chequer-board yield experiments were made. In No. 1 experiment 145/46 was tested against S.145. In No. 2 experiment it was tested against 145/13/10 and 145/15. There were six rows each of two single plants of 145/46. In the field plots 145/46 was alternated with 145/15.

× 14/145

1915. Chequer-board yield experiment of 145/46 and 145/46/55. '55' was one of a number of plants selected from single plants of '145/46' for short necks and high migration.

1916. No chequer-board yield experiment. 145/46/55 was alternated in south side plots in the nursery with 145/46—20 rows each.

1917. No chequer-board yield experiment. Nine rows of 145/46/55 were alternated with 145/46, dibbled across the cage. At harvest the produce of 145/46/55 was found to be higher than that of 145/46. The weights respectively were 4 lbs. 2½ oz., and 4 lbs. o oz.

1918. The family of the plant numbered '145/46/55' was finally selected as the best and was multiplied in successive years. No chequer-board or field trials. '145/46/55' was drilled across the cage with 'S.145' as control.

N.B.—The war of 1914–18 interfered with the further selection of this sub-race, but when systematic work was resumed in 1919 the stock was submitted to field trials.

1919. Three chequer-board yield experiments were made; also field experiments with hand-drill.

1920/23. Chequer-board yield experiments. '145/46/55' was tested against the original Plumage-Archer parent stock by the half-drill strip method and in each of these years proved to be superior both in yield and quality of the grain. In three years out of four it gave higher yield than 'Plumage-Archer 1914'.

1924. Distributed as 'Plumage-Archer 1924'.

N.B.—This race was tested for several years at the N.I.A.B. stations before distribution. Over a series of these trials it was found to be more uniform in character and of better malting quality than 'Plumage-Archer 1914'.

After its distribution it was very thoroughly tried out against Spratt-Archer between 1930 and 1932 at all six N.I.A.B. stations. The results are given in *Journal N.I.A.B.*, vol. 3, No. 4, 1934. They showed quite conclusively that it was inferior in yield and no better

in quality than Spratt-Archer, and I came to the conclusion that perhaps 'single plant selection' had been carried too far and that the race was too homozygous, in other words 'too well bred'.

Description

This is a wide-eared race. As a growing crop, except that it is more even in height, it is almost indistinguishable from 'Plumage-Archer 1914' and probably best suited to the same type of soil. It is more uniform than '145' and has a higher migration coefficient, for which character it was selected after a more exhaustive method than had hitherto been adopted.

GOLDEN ARCHER (35/F.)

This is a hybrid resulting from crossing Spratt-Archer 37/6 with Plumage-Archer 25/1. It is not the progeny of a single plant, but a mass selection—the progeny of a number of F.2 plants carried on to the F.3 generation. The ears are of the type var. *nutans*.

It was raised and multiplied with the view of obtaining a race more nearly resembling the old Chevalier than any of the barleys at that time in cultivation and was specially selected for combined malting quality and vegetative vigour.

History

×35

1923. F.0. Spratt - Archer 37/6 (n) × Plumage - Archer 25/1 (w). 3 grains planted.

> *S.A.* 37/6 *is a hybrid selected from the progeny of a cross made in* 1908 *between* (1) *a selected plant of Irish Archer I and* (2) *a selected plant of Spratt barley by Dr. Hunter, of the Plant Breeding Institute, Cambridge, and late of the Irish Department of Agriculture. The first distribution of this hybrid race was made in* 1921 *in Ireland, and in* 1922 *in this country.*
>
> *P.A.* 25/1 *is a wide-eared selection from a* 1916 *cross of 'Plumage-Archer* 1924' (145/46/55) *with Biffen's* '59/7' (*the best of the Plant Breeding Institute's* [*Cambridge*] *narrow-eared cultures at that period*).

1924. F.1. 3 plants—35 ears—all narrow (S.A. type).

× 35

1925. F.2. 35 ears sown in 35 rows produced 340 plants (showing no Mendelian ratios). The best ear from the best plant of each row was selected for nursery cultivation; the remainder were separated into four groups, viz., Chevalier, Archer, Intermediate, and Plumage-Archer types.

1926. F.3. 60 single plant F.2 cultures were grown in the nursery (of which 40 were of Archer type). One drill of each of the above four types was sown in the field and from the Chevalier type a further selection was made. The result was 7½ lbs. seed, which when grown on resulted in '35/F.'

1927. F.4. Cage selection from F.3's; from these plots were extracted 35/51 and 35/7. 35/F. was tried against Spratt-Archer and Plumage-Archer in a chequer-board plot (20 plots each).

1928. F.5. Half-drill strip yield trial comparing '35/F.' with 'Plumage-Archer 1924'. Chequer-board trial and multiplication plots.

1929/30/31. F.6, 7, 8. Chequer-board trials at Warminster and large field-scale trials at Saxlingham, Norfolk; also trials at N.I.A.B. stations.

1932. F.9. 35/F. was distributed from produce of above Norfolk trials under the name of 'Golden-Archer'.

Description

This is a narrow-eared race. It possesses some of the good qualities of each of its parents. The ears are of the Spratt-Archer type, but slightly more variable. Mass selected races cannot necessarily be as uniform in minor characters as single plant progenies, but they are perhaps more prolific. As with all hybrid races the individual plants vary slightly in character, but the extra vigour of the plants more than compensates for the inevitable slight variability. The grain resembles Spratt-Archer in colour and general appearance. It ripens at Warminster a few days earlier than Spratt-Archer and about the same time as Plumage-Archer.

Fig. 45.—Golden-Archer.

To face page 302

ANALYSES OF GRAIN

		Races	Nitrogen per cent.	1,000 corn weight grammes
1927.	Chequer-board . .	S.A. 37/6	1·77	33·8
		P.A. 1924	1·50	30·7
		35/F.	1·59	32·3
1928.	Chequer-board No. 1.	S.A. 37/6	1·59	42·4
		35/F.	1·39	40·9
	Chequer-board No. 2.	P.A. 1924	1·35	45·4
		35/51	1·43	43·0
1929.	Chequer-board No. 1.	S.A. 37/6	1·59	40·7
		P.A. 1924	1·32	39·2
		35/F.	1·37	38·15
		35/51	1·36	37·7
	Chequer-board No. 2.	S.A. 37/6	1·57	41·3
		P.A. 1924	1·34	39·9
		35/F.	1·42	39·0
1930.	Chequer-board . .	S.A. 37/6	1·78	41·0
		P.A. 1924	1·45	36·7
		35/F.	1·47	36·7
		35/51	1·49	36·4
	Half-drill strips .	S.A. 37/6	1·39	40·1
		35/F.	1·23	38·1
		35/51	1·21	37·9

N.B.—Differences in quality of grain between 35/F and 35/51 are negligible.

TABLE XLIV.—Results of Half-drill Strip Trials of Spratt-Archer, Plumage-Archer and 35/51 at Six N.I.A.B. Stations in 1930.[1]

Stations	Average yields of all races	Comparative dry weights of grain (S.A. = 100)			
	Cwts. per acre	S.A.	P.A.	S.A.	35/51
Cambridge .	22·3	100	106·7	100	112
Long Sutton	21·6	100	107·0	100	97
Good Easter	19·9	100	89·1	100	100
Cannington	16·9	100	89·0	100	101
Newport .	16·5	100	87·8	100	97
Sprowston .	15·9	100	81·3	100	117
Averages.	18·8	100	93·5	100	104

Differences of about 3 *per cent. in* each *comparison are probably 'significant'. The differences in the 'averages' are certainly 'significant'.*

NOTE.—The year 1930 was not a favourable year for Plumage-Archer in most districts.

'PLUMAGE-ARCHER 1935' (35/7)

This is an 'extracted pure line'—the progeny in the F.4 generation of a selected F.2 plant (from about 100 plants). It resulted from the cross-fertilization of Plumage-Archer 25/1 and Spratt-Archer 37/6.

Plumage-Archer 25/1 = ×14/145/46 × Biffen's 59/7.

History

×35

1923. F.0. Plumage-Archer 25/1 × Spratt-Archer 37/6.

1924. F.1. 3 plants—35 ears—all narrow (S.A. type).

1925. F.2. 35 cultures—324 plants. Ears and straw of each *plant* weighed.

1926. F.3. 324 cultures. Ears and straw of each *culture* weighed.

[1] These figures (and those given in Tables XLV, L and LIX) were kindly supplied by the National Institute of Agricultural Botany, Cambridge.

× 35

1927. F.4. 60 cultures seeded from 60 selected F.3 cultures. Square-yard plots of each in chequer-board with parents as controls.

1928. F.5. From the above 60 F.4 cultures '35/7' was selected as the best wide-eared barley. 16 plots were grown in chequer-board with Plumage-Archer 1924, Plumage-Archer 25/1 and Spratt-Archer 37/6 as controls. Grain and straw of each plot were weighed and the following determinations made:

Y. = Yield of grain per cent.
M. = Ratio weight ears to total produce per cent.
N. = Nitrogen per cent. of dry grain determined on each of $4 \times 16 = 64$ plots.
Wt = Weight per 1,000 corns (grammes).

		Average		
Races	Y.	M.	N.	Wt
P.A. 1924	100	47·4	1·36	42·2
P.A. 25/1	96	48·7	1·47	43·2
S.A. 37/6	90	44·5	1·59	42·4
35/7	101	50·0	1·38	44·9

1929. F.6. 20 plots in chequer-board with controls as above.

		Average		
Races	Y.	M.	N.	Wt
P.A. 1924	100	57·6	1·32	39·2
P.A. 25/1	108	58·2	1·40	40·8
S.A. 37/6	106	52·6	1·59	40·7
35/7	110	59·1	1·35	40·8

1930. F.7. 20 plots in chequer-board with P.A.1924 and S.A.37/6.

		Average		
Races	Y.	M.	N.	Wt
P.A. 1924	100	52·6	1·45	36·7
S.A. 37/6	95	50·4	1·78	41·0
35/7	109	55·0	1·50	40·7

1931. F.8. 16 plots in chequer-board with controls as above.

		Average		
Races	Y.	M.	N.	Wt
P.A. 1924	100	48·9	1·60	35·7
S.A. 37/6	99	44·4	2·03	37·8
35/7	108	51·8	1·55	39·0

Field-trial—alternate half-drill strips.

Races	Qrs. per acre	Average Y.	N.	Wt
P.A. 1924	4·89	100	1·28	34·8
35/7	5·88	120	1·24	37·1

×35
1932. F.9. Chequer-board experiments ruined by late sowing and adverse harvesting.

2 acres of 35/7 seeded from field experiment plots of 1931 yielded 9½ quarters drilled in 15-inch rows. Yield and nitrogen content were good under the prevailing conditions which were favourable to high nitrogen.

Average N.	Wt
1·52	44·5

2 acres were grown by Mr. T. H. Rawle, Porlock, Somerset, which gave a heavy yield. Sample excellent.

Average N.	Wt
1·36	44·1

1933. F.10. 20 plots in chequer-board, controls P.A.1924 and S.A.37/6.

Races	Y.	Average M.	N.	Wt
P.A. 1924	100	51·4	1·21	38·9
S.A. 37/6	86	44·9	1·61	42·6
35/7	102	52·0	1·28	40·8

20 acres grown by Mr. Rawle, seeded from two-acre crop of 1932.

Average N.	Wt
1·26	41·8

Very good sample—valued for malting at 56s. per quarter.

Field trial half-drill strip.

Races	Y.	Average N.	Wt
P.A. 1924	100	1·33	41·2
35/7	128	1·19	41·3

×35
1934. F.11. 20 plots in chequer-board.

Races	Y.	Average M.	N.	Wt
P.A. 1924	100	56·9	1·45	41·8
35/7	107	57·8	1·49	42·2

1935. F.12. Half-drill strip trials at Warminster. Trials at six different stations conducted by the N.I.A.B. with 'P.A.1924' as control. Some of these latter results, together with the nitrogen content estimated for the Institute of Brewing Valuation Committee, are given below.

35/7 was distributed in this year as 'Plumage-Archer 1935'.[1]

NOTE.—*Breaking-strain* test of rachis on 1932 crop of 35/7 and P.A. 1924 showed that the rachis of 35/7 were very much tougher, which means less loss in harvesting and threshing. *Lodging.*—Both in cage and field trials 35/7 stood better than P.A. 1924 and much better than S.A. 37/6.

TABLE XLV.—N.I.A.B. Spring Trials, 1935

Stations	Races	Straw	Grain	M.	N.
		cwts.	cwts.	per cent.	per cent.
Cambridge .	35/7	24·8	29·2	54·1	1·59
	P.A. 1924	23·8	27·3	53·4	1·60
Norfolk .	35/7	10·0	17·5	63·6	1·31
	P.A. 1924	8·1	13·4	62·3	1·35
Yorks .	35/7	11·3	21·7	65·8	1·41
	P.A. 1924	12·3	20·8	63·0	1·41
Somerset .	35/7	26·1	29·0	52·6	1·43
	P.A. 1924	30·0	26·9	47·3	1·60
Hants .	35/7	15·5	20·7	57·2	1·46
	P.A. 1924	18·1	19·4	48·3	1·60
Salop .	35/7	18·0	24·5	57·6	1·27
	P.A. 1924	17·8	21·4	54·6	1·35

[1] This race gave higher yields in the N.I.A.B. 1932 spring trials at all six stations than any other race tested, a result which, I think, has never before occurred.

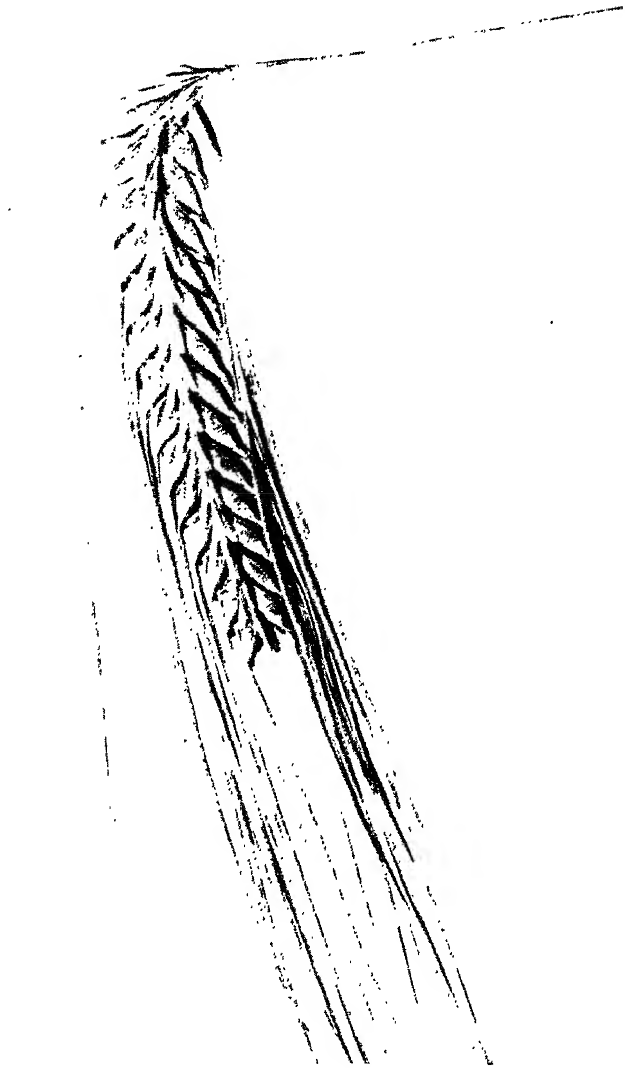


FIG. 46.—Plumage-Archer, 1935.

To face page 308

The nitrogen content of 35/7 is lower than that of the control race at five stations and equal at one. The migration factor is higher at all stations than the control. The yield is higher at all stations.

Description

'Plumage-Archer 1935' is a wide-eared hybrid race, selected for superiority in those factors of productivity and of malting quality which have proved to be the most important.

It inherits the tough ear stem of the Spratt-Archer parent. In other respects it resembles Plumage-Archer.

A study of the cultures of this hybrid race in the nursery and in the field lead me to believe that it is a good all-round barley for soils of medium fertility and in average seasons in this country. I think it would not be suitable for such light soils or for conditions under which yields of not more than 30 to 36 bushels per acre can be expected. Under such adverse conditions either Spratt-Archer or Golden-Archer would give better results.

GOLDEN-ARCHER 35/51S.

× 35.—35/51S. is the progeny of a single F.5 plant selected from the progeny of one F.2 plant of 35/51.[1]

In 1932 and 1933 it gave significantly higher yields in the chequer-board trials than Spratt-Archer.

There was a half-drill strip trial against Golden-Archer 35/F. in 1934. In 1936 there was a chequer-board trial and a spring-sown half-drill strip yield trial.

Eleven acres of this race were grown in Essex in 1934 and the yield and quality were reported to be good.

It differs from 'Golden-Archer 35/F.' in that it is a single plant selection, whereas 35/F. is a mass selection.

It was distributed as 'Golden-Archer 35/51S.' in 1938.

[1] '35/51' was discontinued as it proved to be no better than 'Golden-Archer 35/F.' and not as good as '35/51S.'.

Description

This race is probably an improvement on the original stock. It is a narrow-eared race with a brighter coloured grain than Plumage-Archer. It ripens earlier than the latter. It was selected for high-malting quality combined with good-yielding capacity and does well on a wide range of soils. The ears are of the 'Archer' type. It is more uniform in appearance than 'Golden-Archer 35/F.', but slightly inferior in quality, probably due to over-selection.

×54/12/3

This is a selected hybrid wide-eared barley: the progeny of a single F.3 plant of Plumage-Archer 1924 and Spratt-Archer 37, No. 3.[1]

×54

History

1931. F.0. Plumage-Archer 1924 ♂ × Spratt-Archer 37, No. 3 ♀—9 seeds were fertilized on 2 plants of S.A.

1932. F.1. 9 plants—6 with narrow and 3 with medium ears. There were 47 ears in all.

N.B.—No doubt there were latent factors deriving from one or both of the F.2 plants, P.A. 1924 or S.A. 37, No. 3, giving rise to ears of intermediate width in ×54. There are various heritable degrees of width of ear (due to varying length of internodes) amongst varieties of barley and it is probable that more than one latent factor controlling ear-width was present in one or both parents.

1933. F.2. There were 47 cultures, each seeded from one ear of F.1. 10 grains were planted in each of the 47 rows with alternating rows of Golden Archer as control. The 47 rows (470 grains) produced 432 ears, averaging 9·2 ears per row. There were 197 plants with narrow ears, 120 with medium ears and 115 with wide ears. This is approximately a frequency of the order of 1D, 2DR, 1R—with Wide as recessive if half the Narrows and all the Mediums were DR. Subsequent results, how-

[1] Spratt-Archer 37, No. 3, is a re-selection (by Mr. M. Caffrey of the Albert College, Glasnevin) made in 1921 out of the mixed bulk which had been kept growing in Eire from the original Spratt-Archer cross made by Dr. Hunter at the Cereal Station, Ballinacurra, Co. Cork.

ever, showed that in this case all wide-eared plants were not recessive in the sense of yielding only all wide-eared progeny. Not one of the 47 cultures gave plants which were either all narrow, all medium, or all wide. Every culture contained plants with either two or three types of ears, and in subsequent generations many wide-eared plants proved to be heterozygous in respect of ear-width.

The results obtained do not in fact appear to be consistent with generally accepted theories of transmission of morphological characters.

Determinations were made on each of the 47 cultures (54/1–54/47) of (1) number of ears of N., M., W. types; (2) weight of stems; (3) weight of ears.

Eight surviving plants of this F.2 culture gave the following results:

	Narrow	Medium	Wide	Total	Mean of 2 adjoining rows of G.A., one each side	Average of 47 cultures	Average of 48 G.A. controls
No. of plants	2	2	4	8	9	9·20	9·25
No. of ears	5	6	18	29	24·5	22·40	22·60
Wt. of stems (grms.)	6·0	8·0	25·8	39·8	34·8	31·80	30·50
Wt. of ears (grms.)	7·2	9·2	29·6	46·0	32·1	33·70	30·20
Wt. of plants (grms.)	13·2	17·2	55·4	85·8	66·9	65·50	60·70
Average Totals							
Avg. no. ears per plant (d)	2·5	3·0	4·5	3·62	2·72	2·43	2·44
Avg. wt. per ear (e) grms.	1·44	1·53	1·64	1·61	1·31	1·50	1·34
Yield = wt. ears per plant (y) grms.	3·60	4·00	7·40	5·75	5·25	3·66	3·27
Migration Coefficient (M) per cent.	54·5	53·5	53·4	53·6	48·0	51·4	49·7

These results show definite evidence of hybrid vigour in F.2.

The correlation coefficients have been calculated for all combinations of the factors, d, e, y, M, based on results obtained from yield experiments in the barley nursery during twenty-one years. Results of 54/12 are exceptionally promising for yield of progeny, but they refer to only eight plants and may therefore be wholly

(or very largely) due to environmental conditions, notwithstanding every effort to eliminate the differential effects of such conditions. Several other of the F.2 plants yielded progeny more or less comparable to the above.

× 54

1934. F.3. 120 ears were selected from the progeny of 20 F.2 plants as comparing best with the control rows and were used for seeding 20 plots in a chequer-board yield experiment. Each of the 20 plots consisted of 6 rows of 18 plants—18 grains for each row from a single F.2 ear. These 20 plots were distributed systematically with 20 plots each of 7 other races known to be high yielders. There were 160 plots in all. The *gross* yield of × 54 was compared with that of the 7 other races. From these 20 × 54 plots the parent culture of '54/12/3' was selected for extra high yield (67·4 grammes) from plot 64, row 3.

It may be noted that all the 7 races which were compared with × 54 were races cultivated by growers in various parts of the U.K. and Eire.

Weather and other conditions had the effect in this year of levelling down the yields of all these chequer-board experiments to an average equivalent to 20·6 cwts. per acre with no significant differences between the races.

The average yield of barley for England in 1934 was 16·9 cwts. per acre.

Averages of some of the results are given below:

	1934 average per plot		
	All eight races	× 54	× 54's placing
No. of plants per plot .	103·4	103·5	5
Ears per plant . . .	2·07	2·00	7
Weight per ear (grammes) .	1·19	1·28	1
Yield (grammes) . .	254·40	265·80	1
Migration (per cent.) .	56·4	55·9	4

1935. F.4. In a chequer-board experiment of 128 plots, 64 plots of × 54 were seeded from 9 F.2 cultures [1] of × 54 selected from the 1934 F.3 cultures. 16 plots each of four other races were alternated systematically with

[1] *As between the* 9 *selected F.*2 *races of* × 54 *there were large significant differences: the indication being that amongst these* 9 *some were likely to prove higher yielders than others.*

those of ×54. The four races used were Plumage-Archer 1924, Plumage-Archer 1935, 35/51S., Spratt-Archer 37, No. 3: all proved high-yielding races in previous trials at Warminster and at the N.I.A.B. stations in other localities.

The average comparative yields were in the following order:

16 plots Plumage-Archer 1924 . .	100
16 plots 35/51S.	99
16 plots Plumage-Archer 1935 . .	97
16 plots Spratt-Archer 37, No. 3 .	92
64 plots ×54	95

Differences of 5 *per cent. or less are not 'significant'.*

×54

1936. F.5. Five of the above-mentioned ×54 F.2 races, including one selected F.3 culture of 54/12, were included in a chequer-board trial of 160 plots with the races tried in 1935. In addition to counts and weights of averages per plot of (a) viability—number of surviving plants; (d) number of ears per plant; (e) weight per ear; (y) weight of ears per plot (all heritable characters and factors of productivity), determinations were made of nitrogen content of grain used for seed and of the produce. The results are given in Table XLVI below.

TABLE XLVI.—Warminster Plots, 1936. Chequer-board trial for 54/12/3 (Y. = 100)

Races	Plots	Type ear	Y. per cent.	a	d	e grms.	M. per cent.	N. per cent. seed	N. per cent. crop
54/12/3 (control) .	5	W	100	100·6	1·76	1·30	52·3	1·26	1·53
P.A. 1935 .	20	W	98·1	96·6	1·79	1·31	54·5	1·43	1·57
P.A. 1924 .	20	W	96·0	98·2	1·80	1·25	51·7	1·43	1·58
54/10/3 .	20	W	93·0	95·9	1·73	1·30	52·7	1·40	1·57
54/10/2 .	20	W	92·9	95·4	1·73	1·29	52·2	1·38	1·59
G.A. 35/51/S.	20	N	92·6	96·8	1·83	1·21	51·5	1·45	1·64
54/12/1 .	20	N	90·9	93·4	1·75	1·28	51·4	1·41	1·60
54/13 . .	15	N	89·4	93·7	1·80	1·23	50·6	1·37	1·55
S.A. 37, No.3	20	N	88·6	94·7	1·73	1·25	50·8	1·44	1·58
	160								
Averages (of races)			93·5	96·2	1·76	1·27	52·0	1·40	1·58

TABLE XLVII.—Warminster Nursery Chequer-boards, 1937–40 and Field Half-drill Strip, 1939

54/12/3. Y. = 100

	54/12/3		P.A. 1935		S.A. 37, No. 3		Average of 8 races	
	Yield	N. per cent. crop	Yield	N. per cent. crop	Yield	N. per cent. crop	Yield	N. per cent. crop
1937. F.6—20 plots of each race	100	1·30	99·3	1·38	95·0	1·39	93·6	1·38
1938. F.7—20 plots of each race	100	1·26	99·7	1·36	98·0	1·36	99·0	1·34
1939. F.8—20 plots of each race	100	1·33	98·9	1·42	89·1	1·51	90·9	1·50
Field half-drill strip, 16 each race . . .	100	1·27	98·0	1·38	..	..	..	..
1940. F.9—20 plots of each race	100	1·41	104·5	1·50	86·5	1·46	92·7	1·48
Averages .	100	1·31	100·1	1·41	92·2	1·43	..	..

TABLE XLVIII.—1938 and 1939 Warminster Half-drill Strip Trials of 54/12/3 and P.A. 1935 (Control)

		1938		1939	
		P.A. 1935	54/12/3	P.A. 1935	54/12/3
Total weight grain (raw) as threshed (lbs.) . . .		294·0	315·2	566·0	579·0
Total weight straw (raw) (lbs.)		417·5	425·7	808·0	753·5
Moisture per cent. grain (dry) .		19·9	19·3	16·3	16·7
Migration per cent. . .		41·3	42·5	41·2	43·4
Nitrogen per cent. (dry)	Seed	1·35	1·43*	1·34	1·30
	Crop	1·34	1·30	1·38	1·27
Weight per 1,000 corns (dry) grammes	Seed	35·7	46·7*	37·8	37·7
	Crop	37·8	37·7	37·9	35·7

* 54/12/3 seed was the produce of a plot drilled in 1937 in one-inch drills, which accounts for the large grain.

× 54
1937/40. F.6/F.9. In each of these four years '54/12/3' was grown in 20 plots systematically distributed in a chequer-board of 160 plots, that is to say, with 7 other races, including in each year Plumage-Archer 1935 and Spratt-Archer 37, No. 3.

TABLE XLIX.—Estimated comparison of 1939 Cage and Field Results for Race 54/12/3

	54/12/3	
	Cage	Field
Weight grain per square yard (grammes)	224	166
Grains per square yard	4,700	3,900
Weight grains per ear (grammes)	1·085	·9
Number grains per ear	22·8	21·0
Number ears per plant	2·05	1·20
Number ears per square yard	206	186
Plants per square yard	100	155

NOTE.—*The results of the chequer-board and half-drill strip experiments given above illustrate a very exceptional series and indicate with a high degree of probability that* '54/12/3' *is particularly well adapted to the conditions of the Warminster nursery and field plots, both in respect of productivity and quality of grain. But quite obviously no one race of barley is best adapted to all conditions of environment and cultivation, just as no one race yields grain best adapted to all possible uses.*

Description

'54/12/3' is similar in general character to 'Plumage-Archer 1935', but gave significantly lower nitrogen content and higher yield in the chequer-board and half-drill strip trials at Warminster. As far as I am able to judge at present this race should be an improvement on the previous wide-eared sorts raised at Warminster.

At time of writing (1941) '54/12/3' *has not been distributed, as owing to war conditions it has not been sufficiently tried out on the large field scale.*

The National Institute of Agricultural Botany, Cambridge, in 1940 included '54/12/3' in their trials at five stations in England with widely different extrinsic conditions. Four races were included in these trials, viz.,

1. Spratt-Archer 37, No. 3 (Control).
2. 54/12/3.

3. 189/90, bred at the Plant Breeding Institute, Cambridge.
4. Kenia, a Danish race with a very short growing period, not at present in general cultivation in Great Britain, but possibly well adapted for late sowing in some localities.

Kenia (the results of which are not given in Table L) gave the highest migration at all five stations, with wide differences in yield.

Records of yields and nitrogen of the first three races are given in Table L below.

TABLE L.—N.I.A.B. Yield Experiment, 1940. Results at five stations [1]—three races

S.A. Y. = 100

		Yield	Nitrogen per cent.	1,000 corn weight grammes	Migration per cent.
Somerset.	S.A. .	100	1·442	37·9	51·8
	54/12/3	97	1·444	40·8	57·0
	189/90 .	96	1·521	40·8	51·3
Hants.	S.A. .	100	1·815	44·1	50·3
	54/12/3	96	1·658	46·4	50·4
	189/90 .	86	2·055	45·7	49·6
Salop.	S.A. .	100	1·385	44·2	52·6
	54/12/3	97	1·296	45·1	58·6
	189/90 .	87	1·524	46·2	55·0
Norfolk.	S.A. .	100	1·597	39·7	57·1
	54/12/3	87	1·551	39·4	60·3
	189/90 .	94	1·598	42·6	56·3
Yorks.	S.A. .	100	1·672	41·9	57·8
	54/12/3	101	1·575	44·6	63·7
	189/90 .	93	1·734	42·2	56·6
Means—all 5 stations	S.A. .	100	1·582	41·6	53·9
	54/12/3	95·6	1·505	43·2	58·0
	189/90 .	91·2	1·686	43·5	53·8
Mean for G.B. N. per cent. .	.	..	1·65	..	..

[1] There were no trials at Cambridge owing to war conditions.

It is seen from the above results that Spratt-Archer is superior in respect of yield on the above soils, but 54/12/3

appears to give better quality. 54/12/3 in four out of five of the trials gave lower nitrogen than the races with which it was compared, and a higher migration coefficient at all five stations, which I think is good evidence that M. is an inherited character.

In view of this and previous data it may now be concluded that Spratt-Archer gives to most growers in Great Britain (and certainly in Eire, where little else but Spratt-Archer is grown) better value per acre than any other race so far (1940) tried out year by year on different soils. But over considerable areas in England (also probably in Scotland) Plumage-Archer and the hybrids raised at Warminster from crossing Plumage-Archer and Spratt-Archer give better value.

NOTE.—54/12/3 was distributed in 1943 under the name of 'Beaven's 1943'. The same year it was included in a combined small-scale and field trial by the Irish Department of Agriculture and Messrs. Guinness in Ireland. It showed up so well in respect of high yield and low nitrogen that further large-scale trials will be continued.

TEST MADE AT WARMINSTER FOR TOUGHNESS OF RACHIS —COMPARING '54/12/3' WITH 'PLUMAGE-ARCHER 1935'

Unfortunately the character of brittle rachis common to H. *spontaneum* has not been completely lost and some of our cultivated races possess it to a more or less limited extent.

In 1939 the following tests were made. 100 ears of each race were taken from sheaves of discarded plants from the 1938 crop yield experiment. The result was as follows:

	'Plumage-Archer 1935'	'54/12/3'
Average weight necessary to break rachis . . .	876 grammes	896 grammes
Rachis broken at base of ear.	3 per cent.	12 per cent.

× 68

This is a hybrid resulting from a cross between Plumage-Archer 1935 and Spratt-Archer 37, No. 3 made in 1938.

At time of writing (1941) this race has only reached the F.3 generation.

CHAPTER XXIX

SIX-ROWED (WINTER) BARLEYS AND NAKED (HUSKLESS) BARLEY RAISED AT WARMINSTER

NEITHER the H. *hexastichum* nor the H. *vulgare* sub-species has been grown extensively in England. Where either has been grown in England it has been autumn-sown and used chiefly as a forage crop. Having been selected for this purpose little attention has been paid to quality, and it has rarely been saleable at a price to make it worth harvesting, except for seed.

Although H. *vulgare* is often spring-sown in Scotland, it is, to the best of my knowledge, rarely spring-sown in England; yet if it were so grown it would doubtless have some points in its favour. It grows more rapidly and matures earlier than two-rowed barley under equal conditions, which is an obvious advantage. Then again the yield of both grain and straw is considerably greater than that of the two-rowed sorts and this might compensate the grower for lower value per unit of weight and for the low price realized.

There are winter and spring sorts of H. *vulgare* and I think there is no doubt that almost any race of barley can be gradually accustomed to either habit of growth. It is doubtful if winter-grown *vulgare* can be made to produce grain of the quality required for malting when grown in this country. It is rare to see samples which compare in respect of quality with the foreign sorts, such as Yerli (Smyrna), or Brewing Californian.

The quality of H. *hexastichum*, however, has often been quite good, although it is not generally of malting-quality standard.

For several years I have had under trial in the nursery chequer-boards and half-drill strip trials a number of established races of H. *vulgare* and H. *hexastichum* with the object of raising a barley for autumn-sowing of good malting quality, suited to our climate, which, in case of need, could take the

FIG. 47.—F.112 (H. *hexastichum*).

o face page 318

place of the six-rowed imported sorts. In addition, I have raised and similarly tested a large number of hybrid races with both autumn and spring sowing, but not one of these has gone into general cultivation.

F.112 (H. *hexastichum*)

In order to discover the parentage of this race one would have to unearth records of about 2000 B.C., because similar barley (quite possibly its progenitors) was found in Swiss lake-dwelling deposits of about that period. It is, however, very similar to imported Chilian barley.

F.112 (bred at Warminster) is the progeny of a plant selected in 1913 from a commercial bulk of Daytown Blue Brewing 1901. If there is any aggregate (which I doubt) on the face of the globe which can claim to be called a 'pure line', or a homozygous race, it is F.112; although in one of the plots at Warminster there appeared one or two individuals of a very similar, but quite distinct race. Whether these were the progeny of individual grains accidentally crossed, or a mutation, I do not know, but such evidence as I have favours mutation.

A vast amount of work has been done with F.112 in the nursery and laboratory at Warminster for the past twenty-seven years. This is certainly a remarkable barley in many respects, more particularly in regard to its vegetative characters and habit of growth. It has a very fine and large root system and stiffer straw than any other race tested at Warminster. It is more prolific in this country than any six-rowed barley grown so far and is almost the most winter-hardy. It requires heavy land, and when sown on strong wheat land it will stand up with a crop of 7 to 9 quarters per acre. F.112 has been fairly extensively grown in the south-west of England, mainly in Dorset and Wilts, and is particularly suitable to the latter district, where the average rainfall is about 50 per cent. higher than, say, Essex, and where a barley coming to harvest in July with a heavy yield is worth more per acre than a barley of better quality which would not stand as well. A small area of this barley is grown every year at Warminster and is usually sown in October.

The defects of F.112 are that it requires a long resting stage

and is subject to attacks of *cladosporium herbarum* in wet seasons, which appears when the grain is almost fully ripe. For this latter reason I have discouraged the spread of it, although some escaped from my plots several years ago. Also, owing to its early ripening habit, a small area of it may be liable to serious damage from birds.

×49

This is the result of a cross between F.112 and 'July' (H. *vulgare*), the object being to combine, if possible, the winter-hardiness of the former with the good malting quality of the latter.

'July' has a short growing period. Its defect is that it is not winter-hardy and fails if it encounters frost.

There were 280 F.2 plants of above cross in the nursery in 1930 and there were 100 cultures under observation between 1931 and 1933. In 1933 (F.5) selected progenies of 15 plants were grown in a chequer-board, and in 1936 the number was reduced to 4, viz., ×49/2/3, ×49/3/4, ×49/10/1, and ×49/24/7:

×49/2/3 (H. *vulgare*) is a single plant selection from above cross. It has a long straw: is even in all stages: and ripens rather later than 'July'. It gives good yield and quality and appears to be almost as winter-hardy as F.112.

×49/3/4 (H. *vulgare*) is similar to 49/2/3, but uneven in growth at all vegetative stages. It ripens early and is of good quality.

×49/10/1 (H. *vulgare*) has shorter and stiffer straw than 49/2/3, but is less even in growth.

×49/24/7 (H. *parallelum*) has longer and weaker straw than the parent F.112, but ripens earlier and gives better yield and quality.

None of the ×49's were distributed, as in 1937 I had a new F.112 × 49/10/1 hybrid, some selections of which appeared to be superior to ×49 and which are still (1941) under trial.

In the light of my own experience I think it unlikely that it is possible to produce a six-rowed barley in Great Britain which could compete with the imported sorts in respect of quality; also the low yields generally obtained in this

FIG. 48.—Beaven's Naked (huskless) barley.

To face page 320

country make production uneconomical under present conditions.

Maybe under some improved farming system new and superior races of autumn-sown six-rowed barleys will be more extensively and profitably grown, especially if the available supply of imported sorts falls off for any reason (as is quite possible), or becomes more costly. What is required is an early-ripening, high-yielding race, with low nitrogen content, which could take the place of Californian.

Some future plant breeder may produce such a race, which will be profitable to growers and also give brewers what they want, if, or when, there is agreement as to what they want. But it is to be remembered that it takes a considerable number of years to raise and adequately test any new race of barley; also it is a costly business and unprofitable to the breeder. But it is 'bread cast upon the waters' which may return to those who come after.

Beaven's Naked (Huskless) Barley

In wheat the caryopsis or true fruit, commonly called the grain of the plant, is loosely enclosed between two chaffy scales, the paleae, and easily shaken from the ear when it is threshed.

In the ordinary barleys grown in this country the fruit of the plant is also a caryopsis enclosed between two paleae, but these when the grain is ripe become fused to the surface of the caryopsis, and cannot be separated from it except by special milling machinery.

There are, however, several varieties, belonging to all the different species of barley, in which the paleae quite as loosely invest the caryopsis as they do in wheat; these varieties are known as naked barleys: the ears give up their caryopses as readily as wheat when threshed.

Naked barleys are extensively cultivated for human food in Japan, and some Himalayan districts.

After twenty years of experimentation I have succeeded in raising a race of this barley which will yield sufficiently well to be profitable to farmers and which will provide raw material of high vitamin content for cereal food in some shape or form. It is a hybrid race selected from the progeny

of some ears received from Dublin in 1934. The ears were the progeny of some white naked barley taken from some black naked received from Kenya previous to that date.

In 1940 this selected hybrid race gave a yield of 20 cwts. per acre on 6 acres of quite inferior land. This is quite an exceptional yield for naked barley grown in this country. Previous races of naked barley gave poor yields and had weak straw. I have now (1941) multiplied this barley up from a single hybrid to 6 tons.

I think this new production should have a future as a nutritive form of human food. The best uses to which it could be put would be in the form of 'flakes' (malted or unmalted according to taste and requirements) for breakfast-food, milk puddings, barley-water, and for thickening soups —all of which I have tried and found satisfactory. For barley-water I think it would be an improvement on pearl barley as the process of removing the husks, which is necessary with pearl barley, would be avoided.

So far there is only a comparatively small acreage of it (under 20 acres), but I hope in the future to arrange for seeding a considerable area. It should be sown early in March at the rate of about two bushels per acre.

An attempt was made at Warminster in 1935 to cross naked six-rowed with F.112, but in 1937 it failed and no further attempt has been made to cross it with any other race.

To face page 322

Fig. 49.—Grains of Beaven's Naked (huskless) barley.

CHAPTER XXX

INHERITED CHARACTERS

INHERITANCE OF PRODUCTIVITY

Tables LI and LII, given below, show some of the differences actually obtained in the total weight of ears on plots of different races, as percentages of the highest, for the years 1919–40 (excluding 1935).

In some instances differences in total weight of ears have been sufficient to justify selecting one or other race for further multiplication. We have, however, to remember that differences in yield of any two races, at one place and in any one year, afford only a moderate degree of probability that they will be repeated under different conditions. This proviso must be borne in mind in considering the results given from year to year.

Table LI.—Warminster Chequer-board Plots. Hybrid and 'Pure' Races. Comparative weight of total ears. Highest =100

No. of Plots	Year	Hybrid Spratt-Archer 37/6	Hybrid Plumage-Archer	'Pure' race Archer	'Pure' race Plumage
20	1919	..	100	89	81
15	1920	..	99	100	86
16	1921	100	97	88	91
16	1922	100	76	89	..
16	1923	..	100	99	76
20	1924	100	86	88	79
20	1925	100	95	92	70
16	1926	100	79	96	63
20	1927	94	100	..	..
16	1928	89	100	..	..
20	1929	100	94	..	..
8 years' average		98	91	..	..
7 years' average		..	..	93	78
5 years' average		100	87	91	..

TABLE LII.—Warminster Chequer-board Plots. Hybrid Races. Comparative weight of total ears. Highest = 100

No. plots	Year	Plumage-Archer 1924	Spratt-Archer 37, No. 3 ex Essex	Spratt-Archer 37, No. 3 ex Ireland	Plumage-Archer 1935	Golden-Archer 35/51/S.	54/12/3
20	1930	92	90	..	100	..	..
16	1931	93	94	..	100	..	..
10	1932	90	100	..	89	..	..
20	1933	98	92	93	100	96	..
20	1934	92	100	100	99	98	..
20	1936	96	89	..	98	93	100 (5 plots)
20	1937	91	86	95	99	93	100 (5 plots)
20	1938	..	..	98	99·9	99·6	100 (5 plots)
20	1939	..	..	89	99	91	100 (5 plots)
20	1940	..	..	83	100	85	96 (5 plots)

Averages:

10 years—1930–40	Spratt-Archer 37, No. 3	93
	Plumage-Archer 1935	99
7 years—1930–37	Plumage-Archer 1924	93
	Spratt-Archer 37, No. 3 (ex Essex)	94
	Plumage-Archer 1935	98
6 years—1933–40 (excluding 1936)	Spratt-Archer 37, No, 3 (ex Ireland)	93
	Plumage-Archer 1935	99·5
	Golden-Archer 35/51S.	94
5 years—1936–40	Plumage-Archer 1935	99·2
	Golden-Archer 35/51S.	92·3
	54/12/3	99·2

Differences of about 10 *per cent. in any one year and of about* 4 *per cent. in the averages for* 8 *years are 'significant'.*

We want a finer 'sieve' than this to justify the expense of multiplying a new race up to the quantity of seed required for field trials and we therefore proceed to certain other biometrical calculations.

If by biometrical analysis of our records we can detect well-marked differences in the behaviour of races in either the seedling or the grain-forming periods, which under the climatic conditions of this country are the critical periods for cereal crops, and if we can make sure that these differences are inherited, i.e. are more or less independent of soil and weather conditions, it will be a great help in shortening the testing period.

These measurements will be the 'tillering' capacity of races; and the migration coefficient, which is the ratio of the weight of the corn to the weight of the entire plant.

Inheritance of Tillering

Both tillering capacity and size of heads are inherited characters. In the case of barley (and probably the other cereals) those races which tiller best generally have the smallest ears and it makes no difference to the ordinary grower, as long as he can get a maximum yield, whether this is due to the number or to the weight of the heads.

The vigour of the individual plant during the first month or so of its life is indicated by the number of its shoots. Again this is dependent on the range and activity of its root system, and each shoot is a potential ear-bearing stem. Without efficient tillering we get poor yields. The number of tillers on each plant depends, however, to a great extent on the soil space and plant food available.

When comparing races in respect of tillering we take the count of the average number of ear-bearing stems per plant. In the cage we get over 300 ears per square yard in some years. The average is about 209. Many fields produce less than this and we have nothing to tell us what the average is, but I doubt if it is as much as 300 per square yard in all Great Britain.

The tables overleaf (LIII and LIV) show the difference in tillering capacity between races for the period 1919–40 (excluding 1935).

These figures provide good evidence that 'tillering' capacity is an inherited character. In the first period (1919–29) Spratt-Archer always leads in this respect, and in the second period (1930–40) it shows a higher average tillering capacity than the Plumage-Archers, but not as high as the re-selected Golden-Archer.

Inheritance of Migration

The predominant factor of productivity in cereals is the grain-forming energy of the individual plants composing the crop. This factor results from a combination of inherited structures.

The migration coefficient is not only a measure of the grain-forming energy of races, but it is necessarily a measure of the comparative yields of grain when the total produce is the

TABLE LIII.—Warminster Chequer-board Plots. Hybrid and 'Pure' Races. Average number of ears per plant (highest in heavy type)

No. of Plots	Year	Hybrid Spratt-Archer 37/6	Hybrid Plumage-Archer	'Pure' race Archer	'Pure' race Plumage
20	1919	..	..	**1·67**	1·46
15	1920	..	..	**2·07**	1·94
16	1921	**3·29**	3·15	3·09	2·95
16	1922	**2·64**	2·31	2·49	..
16	1923	..	1·71	**1·76**	1·42
20	1924	**2·68**	2·46	2·52	2·12
20	1925	**2·35**	2·08	2·16	1·75
16	1926	**2·32**	1·86	2·17	1·71
20	1927	**1·94**	1·85	..	..
16	1928	**2·53**	2·52	..	..
20	1929	**1·87**	1·78	..	..
8 years' average		**2·45**	2·25	..	..
7 years' average		..	..	**2·21**	1·91
5 years' average		**2·66**	2·37	2·49	..

TABLE LIV.—Warminster Chequer-board Plots. Hybrid Races. Average number of ears per plant (highest in heavy type)

No. of plots	Year	Plumage-Archer 1924	Spratt-Archer 37, No. 3		Plumage-Archer 1935	Golden-Archer 35/51/S.	54/12/3
			ex Essex	ex Ireland			
20	1930	2·74	2·77	..	**2·88**	..	..
16	1931	**2·75**	2·66	..	2·60	..	..
10	1932	1·77	**1·90**	..	1·66	..	..
20	1933	2·50	2·50	**2·75**	2·54	2·71	..
20	1934	1·90	2·15	2·12	2·04	**2·18**	..
20	1936	1·80	1·73	..	1·79	**1·83**	5 plots { 1·75
20	1937	1·95	1·97	**2·20**	2·06	2·15	2·06
20	1938	..	..	2·69	2·56	**2·80**	2·53
20	1939	..	..	**2·17**	2·11	2·15	2·05
20	1940	..	..	2·02	2·20	**2·35**	2·08

Averages:

10 years—1930–40	Spratt-Archer 37, No. 3	**2·30**
	Plumage-Archer 1935	2·24
7 years—1930–37	Plumage-Archer 1924	2·20
	Spratt-Archer 37, No. 3 (ex Essex)	**2·24**
	Plumage-Archer 1935	2·22
6 years—1933–40 (excluding 1936)	Spratt-Archer 37, No. 3 (ex Ireland)	2·32
	Plumage-Archer 1935	2·25
	Golden-Archer 35/51S.	**2·39**
5 years—1936–40	Plumage-Archer 1935	2·14
	Golden-Archer 35/51S.	**2·26**
	54/12/3	2·10

Differences of about ·25 *in any one year and of about* ·10 *in the averages for* 8 *years are 'significant'.*

same (as is often approximately the case). It is also generally associated with high quality of grain. With some races this factor frequently outweighs a higher number of ears, or a greater average weight per ear, in another race. The facts are that the dry ears of the plant frequently weigh more than the entire dry weight of the rest of the plant.

To the practical farmer a high migration coefficient indicates that his crop is well 'headed'. This does not necessarily mean that the individual heads are large, but it means that the grain threshes well out of the straw. Farmers are already aware that this is an important seasonal factor affecting yield of grain, even if they are not alive to the fact that it is also a racial character of certain races of the cereals compared with others of the same species. With barley a consistently higher ratio of grain to straw can be obtained in cross-bred races than is present in either of the parent races.

To illustrate the value of the migration factor in barley: my late son-in-law, Professor T. B. Wood, who farmed about 300 acres in Norfolk, had a foreman who was an extraordinarily good hand at estimating the number of sacks which would be threshed out of a stack, but his calculations were entirely upset when they changed over from the race they formerly grew to that of pedigree Archer. There was a difference of 10 to 20 sacks to a stack in favour of Archer. This was simply because this race has an exceptionally high migration, and although, as the foreman said, the size of the stack was such as would lead a practical farmer to judge that it would yield 100 sacks, the yield with this particular race was substantially higher.

In selecting for productivity of grain on unit area I attach great value to the migration factor. Also in the early stages of the selection of races I have found it very useful because it can be determined with a very small 'probable error' for comparative purposes by growing only about 2,000 plants when these are grown under specified conditions, whereas a considerable area is required under ordinary conditions of cultivation to eliminate the error of environmental conditions in estimating the produce of grain on a given area. I also find that for races of similar duration of growing period the migration coefficient is closely correlated with weight of grain on any given area, whilst it is not correlated, or

negatively so, with weight of straw. In other words, the migration coefficient is mainly a racial character, whilst weight of grain on any area, although to some extent related to race, is predominantly determined by environment.

In many cases I have determined the percentage of the ratio of grain to straw on the F.3, F.4 and F.5 generations of my hybrid cultures, and I have always done so for each plot of the chequer-board cultures. The result is written as, for instance, M=50, where the entire dry weight of the plant is 500 and that of the dry ears 250 grammes. This figure varies from about 45 to 55 in different seasons, and as between different races in the same season. For strict accuracy it should be calculated on the weight of grain only, but for comparative purposes there is no appreciable error in using the ear weights instead of the grain weights in the case of barley, because the ratio of the weight of the grain to that of the ear, in the case of two-rowed barley, is constant within narrow limits.

As a measure of comparison between races, which in any one and the same season have been cultivated under approximately equal conditions, the migration coefficient is a much more constant character than either the number of tillers or the size of the heads, and even in different seasons the several races maintain much the same order of merit in this respect, although, of course, all of them may be much better in one year than in another.

Tables LV and LVI—given opposite—illustrate this statement.

It is shown from these chequer-board results that a relatively high or low migration coefficient is an inherited character of certain races. With the exception of the year 1922 Plumage-Archer has in every year the highest migration coefficient. Differences in the migration factor, even on quite small plots, unlike those of the gross weight of grain, are nearly always 'significant'. These differences are such that in the chequer-board plots the odds are often 1,000 to 1 against their being due to chance. There is also good evidence that the migration factor is less dependent on soil effects than is the relative tillering capacity of races.

The migration coefficient does not, of course, always determine relative yields of grain. If the total weight of

Table LV.—Warminster Chequer-board Plots. Hybrid and 'Pure' Races. Average weight of ears as a percentage of average weight of plants (highest in heavy type)

No. of Plots	Year	Hybrid Spratt-Archer 37/6	Hybrid Plumage-Archer	'Pure' race Archer	'Pure' race Plumage
20	1919	..	**57·4**	54·6	54·7
15	1920	..	**47·6**	47·0	46·5
16	1921	57·2	**57·3**	56·5	55·7
16	1922	**50·8**	49·0	49·9	..
16	1923	..	**54·0**	52·9	52·9
20	1924	47·3	**49·1**	47·3	48·0
20	1925	54·8	**58·1**	56·0	57·2
16	1926	48·4	**53·0**	51·4	50·7
20	1927	47·0	**50·3**	..	..
16	1928	44·5	**47·4**	..	..
20	1929	52·6	**57·6**	..	..
8 years' average		50·3	**52·7**	..	..
7 years' average		..	**53·8**	52·2	52·2

Table LVI.—Warminster Chequer-board Plots. Hybrid Races. Average weight of ears as a percentage of average weight of plants (highest in heavy type)

No. of plots	Year	Plumage-Archer 1924	Spratt-Archer 37, No. 3		Plumage-Archer 1935	Golden-Archer 35/51/S.	54/12/3
			ex Essex	ex Ireland			
20	1930	52·6	52·4	..	**55·0**	..	..
16	1931	48·9	46·9	..	**51·8**	..	..
10	1932	59·5	58·5	..	**60·5**	..	..
20	1933	51·4	48·8	48·9	**52·0**	50·3	..
20	1934	56·9	55·6	55·6	**57·8**	55·6	..
20	1936	51·7	50·8	..	**54·5**	51·5	5 plots: 52·3
20	1937	50·9	49·1	48·9	**52·3**	49·6	51·0
20	1938	..	..	54·0	**56·7**	53·8	55·2
20	1939	..	..	44·5	**50·1**	46·1	50·0
20	1940	..	..	53·2	**55·9**	52·8	55·8

Averages:

10 years—1930–40	Spratt-Archer 37, No. 3	51·4
	Plumage-Archer 1935	**54·7**
7 years—1930–37	Plumage-Archer 1924	53·1
	Spratt-Archer 37, No. 3 (ex Essex)	51·7
	Plumage-Archer 1935	**54·8**
6 years—1933–40 (excluding 1936)	Spratt-Archer 37, No. 3 (ex Ireland)	50·85
	Plumage-Archer 1935	**54·1**
	Golden-Archer 35/51/S.	51·4
5 years—1936–40	Plumage-Archer 1935	**53·9**
	Golden-Archer 35/51S.	50·8
	54/12/3	52·8

Differences of about ·7 in any one year and of about ·3 in the averages for 8 years are 'significant'.

the plants, that is, grain and straw together, of any race is very low, even a high migration coefficient will not mean a high yield. For instance, in comparing Spratt-Archer with Plumage-Archer, the greater vigour of the former in the seedling stage and consequent higher plant weight on unit area more often than not compensates for its lower migration coefficient.

There is at present no race known to me in which these two factors of productivity are both at the optimum and which at the same time persistently yields grain of relatively high malting quality. It remains to endeavour to bring about these *desiderata* by further experiments in hybridization combined with biometrical examination of the results.

Inheritance of Nitrogen Content

As in the case of the migration coefficient, so in the case of nitrogen content we are able to determine small differences with a high degree of accuracy in chequer-board experiments, and thus make sure whether these are due to racial or extrinsic conditions.

The results of the chequer-board experiments at Warminster, taken together with those obtained on the field plots, and those carried out by the National Institute of Agricultural Botany, sufficiently establish the fact that relative nitrogen content is an inherited character of races, but of course this can only be established when the races are grown under parallel conditions. Climate, soil, and effects of manures will always be overruling factors.

Tables LVII and LVIII, given opposite, show the differences in nitrogen content between different races for the period 1919–40 (excluding 1935).

These results are fairly good evidence that nitrogen content is an inherited character. In the first period (1919–29) Plumage-Archer—with the exception of four years—has the lowest nitrogen content. In the second period 54/12/3, which was specially selected for low nitrogen, is consistent in this respect and has a lower average nitrogen content than either of the races with which it is compared.

Note.—I have satisfied myself that Spratt-Archer 37/6 has a higher average nitrogen content than the standard race,

Table LVII.—Warminster Chequer-board Plots. Hybrid and 'Pure' Races. Average nitrogen per cent. of grain (lowest in heavy type *)

No. of Plots	Year	Hybrid Spratt-Archer 37/6	Hybrid Plumage-Archer	'Pure' race Archer	'Pure' race Plumage
20	1919	..	1·38	1·46	**1·34**
15	1920	..	**1·78**	2·03	1·90
16	1921	1·81	**1·73**	1·80	1·79
16	1922	2·00	**1·90**	2·10	..
16	1923	..	1·52	**1·46**	1·56
20	1924	1·87	**1·78**	1·89	1·82
20	1925	1·57	1·52	1·54	**1·46**
16	1926	1·71	1·70	1·72	**1·67**
20	1927	1·77	**1·50**	..	..
16	1928	1·59	**1·36**	..	
20	1929	1·59	**1·33**	..	..
8 years' average		1·74	**1·59**	..	..
7 years' average		..	..	1·70	**1·65**

* Low nitrogen indicates good quality.

Table LVIII.—Warminster Chequer-board Plots. Hybrid Races, Average nitrogen per cent. of grain (lowest in heavy type *)

No. of plots	Year	Plumage-Archer 1924	Spratt-Archer 37, No. 3 ex Essex	Spratt-Archer 37, No. 3 ex Ireland	Plumage-Archer 1935	Golden-Archer 35/51/S.	54/12/3
20	1930	**1·45**	1·49	..	1·50	..	..
16	1931	1·60	1·64	..	**1·55**	..	..
10	1932	1·89	**1·75**	..	1·84	..	..
20	1933	**1·21**	1·36	1·39	1·28	1·36	..
20	1934	**1·45**	1·48	1·54	1·49	1·54	..
20	1936	1·58	1·58	..	1·57	1·64	5 plots **1·53**
20	1937	1·43	1·41	1·39	1·38	1·42	5 plots **1·30**
20	1938	..	..	1·36	1·36	1·37	5 plots **1·26**
20	1939	..	..	1·51	1·42	1·61	5 plots **1·33**
20	1940	..	..	1·46	1·50	1·53	5 plots **1·41**

Averages:

10 years—1930–40	Spratt-Archer	1·50
	Plumage-Archer 1935	**1·49**
7 years—1930–37	Plumage-Archer 1924	**1·52**
	Spratt-Archer 37, No. 3 (ex Essex)	1·53
	Plumage-Archer 1935	**1·52**
6 years—1933–40 (excluding 1936)	Spratt-Archer 37, No. 3 (ex Ireland)	1·44
	Plumage-Archer 1935	**1·40**
	Golden-Archer 35/51/S.	1·47
5 years—1936–40	Plumage-Archer 1935	1·45
	Golden-Archer 35/51S.	1·51
	54/12/3	**1·37**

Differences of about ·08 per cent. in any one year and of about ·03 per cent. in the averages for 8 years are probably 'significant'.

37, No. 3, now generally cultivated in England. This fact, however, in no way invalidates the evidence that relative nitrogen content is an inherited character as between the races compared.

The following table shows the inheritance of nitrogen content in two races. 54/12/3 and Spratt-Archer 37, No. 3, (1) in the Warminster chequer-board plots for five years, 1936–40; and (2) in 1940 at five different stations of the National Institute of Agricultural Botany.

TABLE LIX.—(1) Warminster Chequer-board. (2) N.I.A.B., 1940. Lowest in heavy type

	(1) 54/12/3	(1) S.A. 37, No. 3		(2) 54/12/3	(2) S.A. 37, No. 3
1936 . .	**1·53**	1·58	Somerset .	1·44	1·44
1937 . .	**1·30**	1·39	Hants .	**1·66**	1·81
1938 . .	**1·26**	1·36	Salop .	**1·30**	1·38
1939 . .	**1·33**	1·51	Norfolk .	**1·55**	1·60
1940 . .	**1·41**	1·46	Yorks .	**1·57**	1·67
Avg. .	**1·37**	1·46	Avg. .	**1·50**	1·58

Average of 10 *cases:* 54/12/3 . . . **1·44**
„ „ S.A. 37, No. 3 . 1·52

54/12/3 was specially selected for low nitrogen content.

It can now be demonstrated that there are at least six 'characters' in barley which are differentially inherited—all of which have some effect on either productivity (i.e. yield of grain per acre), or on the quality of the grain. These are:

1. Viability—ratio of number of surviving plants on unit area to number of seeds sown.
2. Ear survival—number of ears per plant surviving at harvest to ripe stage.
3. Number of grains per ear.
4. Weight per 1,000 grains.
5. The migration coefficient—ratio of weight of grain to total weight of plant.
6. Nitrogen content of ripe grain.

NOTE.—4 and 6 are criteria of 'quality' of grain.

Other possible inherited variables are: content of potash, phosphates, and other constituents of the grain which may influence productivity or quality; and characters of the stem, leaves, and length of growing period.

All the variable characters may be differentially inherited quantitatively, that is to say, there may be three or more 'degrees' of viability, or of any of the other inherited characters above numerated. The old 'presence or absence' of genes is now exploded.

The average barley acreage in England and Wales over a series of years is about 1 million. The number of plants per acre is about 0·5 million and the number of seeds per plant is about 40. The total number of seeds produced in a year may thus be 2×10^{13}. These, in my opinion, may each possess 20 heritable characters. If the races are now compared merely on 'A' or not 'A' characters, e.g. if one is more or less viable than another, the total number of different possibilities is 2^{20}, which is over a million, while if the characters are continuously variable the odds are many millions to one against the progeny of any one plant being homozygous in all characters.

What then becomes of the idea that there are pure lines (or pure races) of barley, or of any race of plant naturally or artificially hybridized? How then can seedsmen guarantee 90 per cent. purity in what they offer for sale, seeing that even the purest strain can vary in its degrees of a number of characteristics? What is obviously meant is that it is not possible by mere eye observation to pick out more than 10 per cent. of the surviving plants of the resulting crop which differ from the remainder in some observable morphological character, generally (in the case of the cereals) the shape of the ear. But there are other non-observable characters, up to about twenty in number, which may vary independently of the observable characters and which may affect both yield and quality to an even greater extent than the observed characters.

Uniformity of Inherited Characters

There has been some disposition to associate 'heterozygosity', which is the Mendelian term for 'splitting', with increased constitutional vigour. It is fully agreed that the plants grown from the seeds actually resulting from a cross are exceptionally vigorous and there is no doubt that these plants are 'heterozygotes'. This was Darwin's conclusion and it harmonizes with the experience of all breeders.

But it has never been definitely shown that any extra vigour is associated with heterozygosity in succeeding self-fertilized generations of cereals, and it is very desirable that this point should be settled by an extended series of experiments covering the whole ground. I am of the opinion that a certain degree (perhaps a substantial degree) of heterozygosity is desirable in cereals. I suspect (without being at all sure) that the desirable kinds of heterozygosity are in the root system, which has not been selected for and which, in fact, we know very little about. It is quite conceivable that a blend of root characters amongst the individuals of a race would be beneficial.

Most of us would agree that a mixture of barley and oats gives more vigorous plants and more grain per acre three times out of four than either cereal grown separately would give, and, if this is the case, why not a mixture of somewhat differing individuals of the same species? A mixture of races (if it is a judicious blend) will often produce a bigger crop than a 'pure-bred' race.

There is, however, at present rather a craze for purity of race. A grower is inclined to think there must be something very wrong if he gets seed which gives him a crop in which he finds one or two 'rogues' in every hundred plants. It is quite possible that if he could see the internal organs of the plants he would find a great many more. No plant breeder of any kind of grain can guarantee so-called 'purity' even in the growth of a few acres, because there are a score of ways by which a few odd grains may get into any stock, such as by accidental mixtures during storing, drilling, harvesting and threshing. It should be quite understood that some admixture is inevitable in the course of time, and that such as occurs with ordinary care has a quite negligible effect on the value of the crop.

CHAPTER XXXI

INFLUENCE OF RELATIONS BETWEEN INHERITED CHARACTERS

Relation between Migration and Yield

VERY strong confirmatory evidence of a persistent relation between migration and yield is derived from the Rothamsted records of the past ninety years, and is another instance, if any were needed, of the immense debt which agriculture owes to Lawes and Gilbert.

The study several years ago of some old figures of Sir Henry Gilbert's, published in 1884, first suggested to me that the factor of migration might be of great importance in cereal breeding.

The original figures referred to are those for the wheat crop grown at Rothamsted with farmyard manure in the sixteen years from 1848 to 1863, viz., (1) Dry weight of grain per acre; (2) Dry weight of straw per acre; (3) Ratio of grain to straw; (4) Nitrogen as a percentage of dry matter of grain and of straw; (5) Nitrogen contained in the produce per acre of grain and of straw.[1]

From these figures there was calculated the proportion of the total nitrogen of the plant which was accumulated in the grain in each year. This calculation showed a remarkably close concordance between this ratio (which we may call the 'coefficient of nitrogen migration') and the dry weight of the grain per acre. Obviously the 'uplift' of the nitrogenous matter is a function of the individual plants composing the crops, and the definite and persistent relation to the number of bushels of grain per acre was a first hint of the possibility of using a 'migration' factor in selecting races for productivity.

In 1863, the best year of the sixteen, when the dry weight of the grain was 2,442 lbs., no less than 80·4 per cent. of the total nitrogen of the crop was accumulated in the grain; only 19·6 per cent. was left behind in the straw. In 1853, the

[1] *Journ. Chemical Society*, 1884, pp. 305–407.

TABLE LX.—Rothamsted Wheat, 1848–63. Farmyard Manure. Relation of 'Migration' to Yield

Year	(G) Lbs. dry grain per acre	Lbs. dry straw per acre	M. Dry grain per cent. of total dry produce	Averages	Lbs. nitrogen per acre in		Nitrogen in grain per cent. of total nitrogen per acre	Per cent. nitrogen in			Yield of dry grain calculated from N. % of straw	Compared with 1863 taken as 100	
					Grain	Straw		Total produce	Grain	(N) Straw		Calculated	Weighed
1	2	3	4	5	6	7	8	9	10	11	12	13	14
1863	2,442	3,613	*40·4*		37·1	9·0	*80·4*	·76	1·52	*·25*	2,440	100·0	100·0
1854	2,298	3,778	*37·7*	40·2	39·1	13·2	*74·8*	·86	1·70	*·35*	2,140	87·5	94·0
1857	2,212	2,805	*43·8*		43·6	10·9	*80·0*	1·09	1·97	*·39*	1,990	81·4	90·6
1858	2,099	3,269	*39·1*		40·1	15·4	*72·2*	1·03	1·91	*·47*	1,730	70·8	86·0
1862	2,038	3,519	*36·7*		32·0	13·0	*71·0*	·81	1·57	*·37*	2,060	84·2	83·4
1856	1,881	3,587	*34·3*		35·6	13·6	*72·4*	·90	1·89	*·38*	2,020	82·7	77·0
1855	1,872	3,230	*36·7*		41·0	13·9	*74·6*	1·08	2·19	*·43*	1,860	76·2	76·7
1859	1,872	4,078	*31·5*		39·0	16·0	*70·6*	·93	2·09	*·40*	1,960	80·1	76·7
Avg.	2,088	3,484	*37·4*	36·5	38·5	13·2	*74·6*	·93	1·85	*·38*	2,010	82·9	85·5
1861	1,864	2,662	*41·2*		36·0	11·0	*76·1*	1·05	1·95	*·43*	1,860	76·2	76·3
1851	1,731	2,642	*39·7*		27·2	12·7	*68·2*	·91	1·51	*·48*	1,700	69·6	71·0
1849	1,712	2,499	*40·6*		27·0	11·2	*70·6*	·91	1·58	*·45*	1,795	73·4	70·2
1860	1,594	2,924	*35·4*		31·9	16·4	*66·0*	1·07	2·00	*·56*	1,435	58·8	65·4
1850	1,561	2,677	*36·8*		29·0	13·4	*68·2*	1·00	1·86	*·50*	1,630	66·7	64·0
1852	1,429	2,842	*33·6*	32·8	28·7	13·1	*68·8*	·98	2·02	*·46*	1,760	72·0	58·6
1848	1,359	2,477	*35·4*		25·7	12·1	*68·0*	·99	1·89	*·49*	1,665	68·2	55·7
1853	899	2,721	*24·7*		15·8	19·9	*44·3*	·99	1·76	*·73*	880	36·0	36·8
Avg.	1,517	2,681	*36·0*		27·7	14·0	*66·7*	·99	1·82	*·51*	1,591	65·1	62·2

NOTE.—The negative correlation coefficient of 'lbs. dry grain per acre' (G) and 'N per cent. dry straw' (N) is $r = -·885 \pm ·115$ (max.) and the regression equation is $G = 3{,}260\ (1 - N)$. There is no evidence that this correlation applies to barley.

worst year, when the dry weight of the grain was only 899 lbs., only 44·3 per cent. of the total nitrogen was found in the grain, and the remaining 55·7 per cent. was left behind in the straw.

As a corollary to this, whilst the straw in 1863 contained only 0·25 per cent. of nitrogen, in 1853 it contained 0·73 per cent. of nitrogen.[1] In respect of nitrogen content the straw was in this bad year three times as good feeding material, if (as is doubtful) it was as good in other respects. Sir Henry Gilbert noted the frequently increased feeding value of straw in those years when the yield of grain is low.

Table LX shows that the concordance year by year of these factors with the yield per acre is so close that if the relation had been known beforehand it would have been possible to estimate the yield of grain very closely without weighing the crop simply by determining the nitrogen content in an average sample of the straw. In eight years out of the sixteen the yield was within 5 per cent. of the figure obtained by such a calculation, and only in three years was the difference more than 10 per cent. Vice versa, knowing the weight of the grain on an acre, the composition of the straw in respect of nitrogen content could be calculated within 0·1 per cent. of nitrogen, which is no more than the probable error of sampling and analysis.

When we consider that the combined experimental errors in the recorded weights of the crop and in the sampling and analysis of the produce are probably quite 10 per cent., this is a remarkable correspondence. At the same time, it is what might be expected. It demonstrates that as between different seasons the difference in yield of grain on the same land and with the same manuring is far less closely related to the total weight of the plant (grain and straw together) than to the upward migration of the nitrogenous matters mainly formed, first in the stem and leaves, and afterwards transferred to the grain—in a good year to the extent of 80 per cent. of the total, but in a very bad year to the extent of only about half that proportion.

This upward drift of nitrogenous matter is undoubtedly a measure of the activity of the protoplasm of the plant in the critical period of grain formation.

[1] On dry weight of straw.

Now, it does not necessarily follow that the structures and functions of the plant, which are responsible for either good or bad yields in different years, are those in which there are differences as between varieties and races of the same species, giving us persistent differences in potential yielding capacity.

But there is at least a *prima facie* presumption that this is so; and when we find that different races of barley show, in the same season and on similar soil, well-marked differences of the same nature, and that these differences are persistent, we have added confidence in attaching high value to the migration coefficient for purposes of selection.

In practically every season at Warminster since I have made these determinations in systematically arranged nursery and field plots, the highest yields of barley have been given by those races which show the highest migration coefficient.

The converse is not always the case, and the order of merit of all the different races compared has not always been the same in respect of yield and of the migration coefficient, but there has been in every season a general correspondence between the two.

Table LXI opposite shows the correlation between yield of grain and migration for eight races from 1912 to 1919. It also shows that the relation between yield of grain and migration, although not generally as closely parallel as in 1912, has been fairly parallel in other years, and also that the differences between the races, when grown on the same soil, are persistent from year to year with few exceptions.

Relation of Migration to Nitrogen Content

Munro and I, after our fairly exhaustive examination of Rothamsted barley samples (see Chapters XX and XXI), called attention to the fact that high ratio of grain to straw, which is of course consequent on a high migration coefficient, was highly correlated with low nitrogen content of the grain when the comparison was between samples of grain grown under differing extrinsic conditions, that is to say, as in the case of the Rothamsted samples, under a considerable range of weather and soil conditions.

This suggested to me, after I had assembled all my own records of migration coefficients and nitrogen contents of

TABLE LXI.—Warminster Plots—Correlation of Yield of Grain and 'Migration'

1		2		3		4		5		6		7		8	
1912		1913 (*a*)		1913 (*b*)		1913 (*c*)		1914 (*a*)		1914 (*b*)		1915		1919	
100 (H)	*100*	100 (HI)	*100*	100	*95*	100	*100*	100 (H)	*99*	100	*100*	100 (H)	*99*	100 (HI)	*100*
100	*99*	96	*89*	97	*100*	100	*100*	99 (H)	*100*	98	*99*	97	*100*	92	*99*
99	*98*	95	*92*	95	*100*	95	*96*	98	*95*	97	*100*	97 (H	*98*	92 (H)	*97*
99 (PI)	*96*	94 (H)	*93*	93	*95*	95	*94*	97 (HI)	*100*	93	*100*	95 (H)	*100*	91	*98*
95	*96*	93 (PI)	*91*	89	*93*	91	*93*	96 (H)	*98*	92	*98*	92 (HI)	*98*	88 (PI)	*95*
94	*97*	93 (P)	*90*	87	*93*	88	*89*	95	*93*	91	*94*	82	*84*	86	*98*
93	*94*	87	*89*	86	*93*	83	*96*	94	*92*	89	*96*	79 (PI)	*86*	85	*93*
92	*94*	85	*89*	78	*84*	81	*88*	92 (PI)	*92*	75	*84*	78	*85*	81	*95*

NOTE.—The figures in roman type represent yields (the highest taken as 100) and those in *italics* represent the corresponding migration coefficient (the highest taken as 100). In both cases the figures are to the nearest integer. Columns 1, 2, 5, 7 and 8 are averages of 20, columns 3 and 4 averages of 10, and column 6 of 15, square yard plots. The probable error of each of the yield figures is about 3 per cent., and of each of the migration figures about ·4 per cent.

The mean of the correlation coefficients of yield and migration in the 8 experiments is approximately ·8 with a probable error of less than 1. The letters in brackets attached to some of the numbers indicate the same races in successive years.

Hybrids: (H) = P.A. 14/145. (HI) = P.A. 14/46/55.
Parents: (P) = Plumage. (PI) = English Archer.

different races, that it might be worth while to see whether what held good for effects of external conditions also held good as between different races. In other words, do those races which inherit relatively high grain-forming capacity in the individual plants (as we know some races do), which is favourable to the yield of grain, also inherit tendency to relatively low nitrogen content of grain? If so, we should obviously select races in which both these characters appear.

Dr. F. G. Gregory, of the Botany Department of the Imperial College of Science, kindly analysed statistically the records for these two characters of all the races grown at Warminster on twenty-two chequer-boards, each planted with eight races. The period was from 1910 to 1930. It is difficult to make these figures intelligible in the form of a table, but they indicate clearly that races selected for both high migration and low nitrogen content more often than not turn out to be high yielders also.

Relations between Tillering, Migration and Nitrogen as Factors of Yield

High tillering and migration, and low nitrogen content of the grain I have found to be the main factors of yield in barley.

A combination of high value of these factors gave for two years out of three in my nursery plots high value of grain per acre, and I therefore regard these characters as useful to the plant breeder in selecting parent stocks before yield could be equally well estimated.

This method of selection is justified because differences in these three characters, each obviously available, are, I believe, inherited; whereas some of the factors used fluctuate differentially as between races to a much greater extent with soil and season.

Since in practice nine out of ten of the cultures which are raised (even to the chequer-board stage) in experimentation have to be discarded, the factors of productivity and quality which we have considered are helpful, at any rate in a negative sense. A race which gives no indication of inheriting either high tillering capacity, or a high migration coefficient, or a low nitrogen content, may safely be discarded in this stage

of trial. On the other hand, if a race could be produced which inherited all these characters to an over-average degree, it would almost certainly have a higher economic value than any race at present in existence. Such a race has not yet appeared: to expect such a production is perhaps a 'counsel of perfection', but it is worth working for.

Prediction of the Yield of Barley

The breeder of any hybrid cereal requires to adopt methods which will give indications of value at an early stage in the multiplication of his individual plants. Nothing in the way of plant selection can be done until the F.3 generation is reached, and by this time there will be some hundreds of plants, any one of which may be a more desirable parent of a new race than any other. It is impossible to distinguish effectively between inherited and fluctuating differences due to environment at this stage. At least 2,000 plants of any single plant culture must be raised and compared with a similar number of other plant cultures before this distinction can begin to be established and comparisons made of genetic characters. To bring hundreds of cultures to the stage of field trials would require very extensive areas, expenditure and time.

The weight of grain produced on a unit area is given sufficiently closely by the formula $N \times T \times E$, when N is the number of plants per plot, T the average number of tillers surviving to produce ears, and E the average weight per ear.

The same yield is also given by $N \times P \times M$, when N is (as before) the number of plants per plot, P the average weight of the entire plants, and M the migration coefficient (i.e. the ratio of weight of ears to weight of the entire plant). This is therefore TE/P. It follows, of course, that $PM = TE$, and is the mean weight of ears per plant.

CHAPTER XXXII

(1) ORIGINAL OBSERVATIONS ON GENERAL EXPERIMENTAL POLICY. (2) EXPLANATORY NOTES ON AND CONCLUSIONS FROM AUTHOR'S TABLE OF CORRELATION COEFFICIENTS (TABLE A), AND SUPPLEMENTARY TABLES (TABLES B–E), WITH SUMMARY OF CORRELATIONS AND OTHER STATISTICAL RESULTS, BY G. S. PHILLPOTTS

(1)

THE foregoing outline of the Warminster experiments establishes the fact that as between races of barley grown under similar extrinsic conditions productivity is correlated with (1) vegetative vigour (indicated by root and shoot development of individual plants): (2) seed-forming energy (as indicated by the migration coefficient); and that the latter factor is correlated with low nitrogen content, so that in the case of barley there is some correlation between good yield and low nitrogen content.

The compilation and analysis of the factors which affect either productivity or the quality of the seed for industrial uses will provide tasks for many generations of competent plant breeders. Up to the present we have been content to rely mainly on empirical methods and results in our efforts towards crop improvements.

The history of the steady development of some of our crops, e.g. sugar-beet, is an encouragement to continue our efforts.

We have made a big advance in breeding for yield, but no doubt there is still room for a further step forward. The problem for the plant breeder is to find methods to measure racial differences at the seedling and at the grain-forming periods with a view to establishing their heritability early enough to shorten the period of probation.

If we are to make the optimum use of fertilizers we must breed races that will stand up to rich soil conditions. Tillage and suitable races will effect some increase in yield, but a further advance can be made by way of fertilizers.

I have been aiming at stiff-strawed races all along. Plumage-Archer, for instance, stands up much better than does either of its parents. Unfortunately nearly all the very stiff-strawed barleys are bad 'malters', but, notwithstanding this, it is the right aim to have in view. We must discover which are the morphological and physiological characters which help cereals to 'stand up'. I think that anchorage by the root system should be taken into account and I feel sure that it is to more knowledge of the root system that we must look to obtain any considerable advance in these respects.

In breeding for vigour, I maintain that the most important factor is the judicious choice of original parents. You can't put into a race something which is not potentially present in the parents. You can re-combine characters, but you may easily preclude something which is valuable for vigour as well as for quality.

From past records I have observed that the best parent plants are those which give:

(1) Highest number of average ears per plant (tillering).[1]
(2) Highest average weight of ears per plant.
(3) Highest ratio of grain to straw (migration).[1]
(4) Highest average weight per ear.
(5) Low nitrogen content (quality).[1]

The average agricultural worker (like myself) is absolutely incapable of understanding advanced statistical and biometrical theories. He cannot grasp the meanin[illegible]he vocabulary and symbols employed: they only o[illegible]s vision.

I would lay down a few simple rules for the [illegible] experimenter, viz.,

1. Be satisfied to compare two problems at a [illegible]
2. Don't bother your head with any more th[illegible] simplest arithmetic. 'Data' are good [illegible] bad masters, especially 'mathematical' d[illegible]
3. Don't think too much of such terms [illegible] deviation', 'degrees of freedom', or 'rand[illegible]
4. Think only of averages and of differences [illegible] (mean and mean deviations), and of th[illegible]

[1] (1), (3) and (5) appear to be the most reliable inher[illegible] chequer-board experiments.

of the differences between averages as revealed by these mean differences of pairs. Then only three or four symbols will be required, each of which can be visualized as quantities.

5. Repeat and repeat your observations until the mean differences between pairs become negligible compared with the average differences.
6. Rely on repetition and on *intelligent* choice of material and methods to avoid systematic error.

Agricultural experiments can only lead to *approximate* conclusions because of the complexity of the material, therefore complete mathematical accuracy is not possible.

(2)

NOTES AND CONCLUSIONS

(For Tables A–E see End of Chapter)

General Notes on Correlations

I was asked to make out the conclusions to be drawn from the correlations based on the twenty-five years' work in the cage experiments at Warminster shown in Table A. Dr. Beaven had from time to time made out correlations between the more important figures, but unfortunately did not complete all of them for the whole period nor the intercorrelations between each one of the nine different factors which were measured.

Consequently although in the main all the results given below bear out his interim conclusions, yet in a few particulars certain modifications have had to be made.

In addition, where results of Irish experiments (conducted jointly by the Department of Agriculture and Messrs. Guinness) had an obvious bearing on the questions discussed, these have been included as well.

I would like to add that my thanks are due to Mr. E. Somerfield for his advice on statistical points and especially to Mr. John Byrne (both of James's Gate, Dublin) for making out the enormous number of correlations and other calculations upon which these conclusions have been based.

Chequer-board plots were made of different races at Warminster for twenty-five years between 1912 and 1940 (excluding 1916, 1917, 1918), and in 1914, 1921, 1928 and 1929 additional series were added. As a rule each year eight races were grown, but in 1927 only six races were compared, and in the two series of 1928 and also in 1932 seven races were compared. Generally 20 plots were made of each race, making 160 altogether, but this figure was not invariable; the smallest number of all was in 1932, when there were only 10 replications, making 70 plots in the whole chequer-board.

The following figures were measured each year and averaged for all the plots of each race:

1. Number of plants per square yard surviving to harvest.
2. Number of ears per plant.
3. 1,000 corn weight corrected to dry matter.
4. Number of corns per ear.
5. Weight per ear.
6. Total weight per plant.
7. The 'migration' figure, i.e. the weight of ears divided by weight of whole plant.
8. Percentage of nitrogen in the grain, and
9. The yield.

The method of seeding was to sow 108 seeds per square yard, which is equivalent to about 42 lbs. per acre as against the normal agricultural field practice of, say, 140 lbs. per acre, or about 355 seeds per square yard.

In these plots, out of the 108 seeds sown about 95 survived per square yard, or 460,000 per acre; whereas in a field the number surviving is considerably more, say, 680,000 per acre; in the cage experiment 88 per cent. survived, while in a field only about 40 per cent. survive.

The correlations were made by the 'ranking' method; for each factor the lowest would be marked 1 and the highest (with 8 races) 8, and the correlations made by the Spearman formula:

$$\rho = 1 - \frac{6\Sigma(d^2)}{n^3 - n}$$

$$\left(\text{Correction for } m \text{ ties} - \frac{m(m^2-1)}{12}\right)$$

and then each of the 9 factors measured was correlated with every one of the others, thus giving 36 correlations each year, altogether 1,044 correlations from the 29 comparisons (25 years and 4 duplicates).[1] Averages were then made for each of these correlations for the whole 29 cases, and by comparing the number of times in which the correlations were positive or negative one could get an estimate of the probability of such a distribution of positive and negative by chance.

Another interesting comparison made was to see how far ordinary correlations between the yearly averages of these factors (averages of all the races together) compared with those Spearman correlations got above comparing race by race within single years. In Table B all these correlations are given; the top left-hand figure of each space is the average of the 29 ranking correlations obtained in each chequer-board race by race, to the right (in brackets) is given the probability of a chance distribution of positive and negative correlations as uneven as actually occurred in those 29 comparisons; then in the second line on the left the correlations of the 25 years comparing the actual average factors in each year; and to the right a similar comparison made, but by successive differences so as to eliminate a certain amount of periodic changes which might have been expected to take place.

The more important features in that table may be briefly mentioned.

Correlations with Yield

There are significant correlations with the *number of plants* surviving per square yard, both comparing the races and also from year to year.

+·48	(·000)
+·59	+·52

With the *number of ears* per plant the race effect was less marked, but from year to year this factor was very important indeed, as over 50 per cent. of the variation in yield was associated with this feature—good conditions for early tillering are very important for a good yield.

+·30	(·004)
+·74	+·81

[1] All the individual correlations are given in Table E.

Similarly, if these two are combined together and so the *number of ears per square yard* are compared, higher correlations still are obtained, as this figure includes everything in yield except the weight of the individual ears.

..	..
+·82	+·83

On the whole there is a positive correlation between 1,000 *corn weight and yield*, but it is small in all cases both as a racial and seasonal figure.

+·26	(·03)
+·20	+·32

Wide-eared barleys tend to give high 1,000 corn weight but by no means necessarily a good yield, and, again, a race of barley which tillers well, i.e. has many ears per plant, tends to have ($r = -·338$, $p = ·012$) a small 1,000 corn weight; similarly, even from season to season the number of ears per plant tends to give a small 1,000 corn weight, though not significantly ($r = -·354$, $p = ·164$).

The 1,000 corn weight as compared year by year may be regarded as indicating the relationship between the later and earlier conditions of growth. If barley begins to 'shoot' towards the end of June, the number of corns per ear, and so per acre, are probably fixed some time at the end of May or early in June. If weather conditions were good earlier, there will be at that time well-grown plants, a large number of efficient tillers and the prelude to a good number of corns per ear; if, however, afterwards the weather is unfavourable, unless tillers or plants die, adversity decreases the 1,000 corn weight; conversely, with bad early conditions and favourable later ones but too late for appreciable tillering effects, there will only be a few corns, and, consequently, these will increase in size so as to give a high 1,000 corn weight.

The number of *corns per ear* is also significantly correlated with yield as between races, but insignificantly from season to season.

+·27	(·001)
+·23	+·33

The *weight of an ear* is quite important as a racial character, but from year to year the correlation between this and yield is well below significant values though appreciable.

+·37	(·004)
+·26	+·36

The *total weight of a plant* gives the biggest correlation of all for any single factor, both for races and also from year to year; it is a great help to any race to have a large plant to

+·53	(·000)
+·86	+·90

provide the material for a heavy yield; and even more so from year to year good conditions of growth are most important for a heavy crop.

Migration, or the percentage that the ears are of the total plant (excluding roots), is a very important factor between different races; from year to year however it is insignificant.

+·43	(·000)
+·19	+·07

Apparently good and bad years for yield are not produced by variations in the proportion that the plant puts into its ears nearly as much as by the size of the plant. There is a tendency for plants that grow well owing to external circumstances to put a smaller proportion into the ears (correlations −·230, −·225), thus neutralizing some of the advantage that would be got by a larger plant; racially, however, this effect is much smaller, with a correlation of only −·085 between weight of plant and migration. However, if we make out partial correlations between migration with yield and of plant weight with yield, but with the other factor constant (thus including all the yield factors except number of plants), we obtain the following results:

	Correlations				
	Simple r =		Partial		
			At constant	r =	
Migration: yield	+·431		Plant wt.	+·563	
	+·188	+·075		+·765	+·672
Plant wt.: yield	+·529		Migration	+·630	
	+·856	+·905		+·941	+·950

	Regression coefficients					
			Partial			
	Simple		At constant			
1% migration .	+·375		Plant wt.	+·418		Cwts per acre
	+·165	+·078		+·358	+·305	,, ,,
1 grm. plant wt.	+2·32		Migration	+2·50		,, ,,
	+4·18	+4·26		+4·64	+4·57	,, ,,

It will be noticed that at a constant migration per cent. the correlation between plant weight and yield is nearly unity for different seasons, but not nearly as high for different races within years: this of course is due to the high positive correlation between number of plants and plant weight in different seasons, but this is much smaller in the races.

The *nitrogen* of the grain is significantly negatively correlated with the yield as between races, but far from significantly from year to year. This last result is remarkable, as under ordinary field conditions this negative correlation between yield and nitrogen may be marked. Two opposing factors are at work: firstly, the plant tends to absorb the available nitrogen from the ground and in general to divide it to a constant extent between the ear and the rest of the plant, so the higher the yield the lower the percentage of nitrogen in the ear; on the other hand, rich nitrogenous conditions in the ground give a big yield and yet a high percentage of nitrogen. Consequently these small negative correlations from year to year are really only the resultant of greater or of more negative than positive effects in different years.

−·28	(·001)
−·11	−·29

Other Correlations

Number of Ears per Plant—Tillering.—There was a very slight tendency for the *tillering* to be associated with the *number of plants per square yard* in the races; but, as would be expected, more markedly as between years, i.e. if the conditions were favourable less plants died, and there was also more tillering.

+·17	(·13)
+·31	+·53

Per cent. Migration.—A very significant negative correlation with *nitrogen* as between races, but insignificant in seasons. It seems that different races tend to put a similar total proportion of nitrogen in the ears and body, so the greater the proportion the ears are of the plant the less the per cent. nitrogen. As between seasons, however, this is hardly the case.

−·29	(·003)
−·01	−·28

There are positive correlations with average *weight per ear* as would be expected.

+·47	(·000)
+·34	+·57

−·26	(·031)
+·33	−·30

Nitrogen and Ear Weight.—Between races there is a slight negative connection. When comparing races in a chequer-board experiment, the normal effect of a heavy ear being associated with absence of tillering and so with high nitrogen content has but little effect; as between seasons, however, the results are contradictory, very probably for this reason.

At the bottom of correlation Table B a number of figures connected with the standard errors are given. In the upper line the standard errors are shown of the races for each chequer-board experiment. These figures were not made out normally but from the difference between the maximum and the minimum in each, and then from the mean square of these 29 figures the standard error is calculated [1] on the assumption that there were eight races in each comparison. The standard errors in the lower two lines are made directly from the actual yearly figures (25 cases).

In the next line down of Table B, on the left [Standard Errors Ratios (A)], it will be seen that the standard error of races within the year is about half of that of the actual from year to year, the ratios generally varying from about ·4 to ·6, but in the number of corns per ear the standard error of races inside the year is practically the same as that of the averages from year to year.

Next on the right, comparing the standard error of successive differences between years with that of the actual years, if there were no connection from year to year one would expect the ratio to be about 1·4. Actually it will be seen that as a rule the figure is considerably higher than this, tending to show that there are negative connections between weather or other conditions from year to year which are sufficiently great to more than overcome the tendency for the quality of the races tested to be positively connected from year to year—and probably the inherent cultural conditions as well.

If we compare in the last columns the average figures for

[1] 'Probability Integral of the Range in Normal Samples' (E. S. Pearson and H. O. Hartley, *Biometrica*, vol. 32, p. 308).

the first and second halves ($12\frac{1}{2}$)[1] of the 25 years it will be seen that on the whole there is no difference in the number of plants per square yard, but the number of ears has increased appreciably, i.e. races with more tillering have been selected, but with a smaller increase in the total weight of the plant, and with decreases in the weight per ear, number of corns per ear and 1,000 corn weight.

These features are of course associated with one another: increased tillering tends to reduce the 1,000 corn weight and the number of corns per ear with resultant greater loss of weight per ear. There has also been a marked rise in the migration coefficient and a fall in the nitrogen content, both of course the result of selection of races. The yield, however, shows only a very slight rise compared with what would be expected from the increase in tillering and migration, presumably due to exhaustion of the soil in the cage.

Table C gives the regression factors corresponding with the correlations in Table B. Of course both correlation and regression coefficients are equally useful in their own way, but from different standpoints.

Thus, to give an illustration in mortality figures, a Medical Officer of Health in Europe would normally find a high positive correlation from year to year between the number of cases of influenza and the general death rate from all causes, but an extremely small one with typhus, and so would regard influenza as much more important; whilst a pathologist might be more interested in typhus on account of the regression factors; with influenza it would be of the order of one case giving ·01 death but with typhus ·5.

Further, in certain cases, with the same disease the regression coefficients may give much more striking information about a change than the correlation figures; thus with the use of antitoxin treatment the deaths from diphtheria as a proportion of the total death rate (corresponding with correlation figures) fell quite appreciably; but the case mortality (i.e. regression coefficient) fell very much more—it was of the order of ·3 and became more like ·03 (the apparent number of cases having risen very considerably).

So it is with the figures under consideration; under ordinary conditions Table B is that which is of most interest as it tells

[1] i.e. dividing the thirteenth year between the two periods.

one directly what proportion of the ordinary variations of yield, for instance, are associated with the ordinary variations in other factors and so their relative importance (i.e. the Medical Officer of Health's attitude). But again, on some occasions the regression factors (Table C) may add fresh evidence that shows fundamental differences in the conditions of growth.

Number of corns per ear and yield			
Correlation r =		Regression 1 corn per ear gives .... cwts. per acre	
+·267		+·328	
+·231	+·335	+·693	+1·47

Thus, here the correlations between the number of corns per ear and the yield are very similar both in races and in years, but the regression factors show that from year to year the actual influence per corn on the yield is from two to four times as great as racially within a year—within a year the advantage got by extra corns per ear is nearly counterbalanced by less ears per plant and per square yard, but from year to year extra corns tend to be a sign of good growing conditions and so of heavier corns and ears and yet as many or more per square yard.

As the racial correlations between Yield–Nitrogen–Migration are very significant it was felt worth while to make out multiple correlation coefficients and regressions for Yield with Migration and Nitrogen (with the yearly figures the correlations were so small and insignificant that any regression figures would be worthless):

Starting with the simplest method we can calculate from these average correlations—

Yield : per cent. M. $r = +{\cdot}431$
Yield : per cent. N. $r = -{\cdot}285$
Per cent. M : per cent. N. $r = -{\cdot}287$

—and from these we get a multiple correlation of Yield with Nitrogen and Migration of $r = {\cdot}463$; and a regression equation of Yield in cwts. $= 8{\cdot}51 + {\cdot}325$ per cent. M. $- 3{\cdot}287$ per cent. N.

with error of prediction 1·33 cwts. per acre; but it was thought that taking average correlations might obscure much of the relationship and so two other methods were tried.

1. By making out the 29 multiple correlation coefficients of each chequer-board and from $\sqrt{\text{Av of } r^2}$ we get $r = \cdot669$, with S.E. of yield$=1\cdot49$, error of prediction 1·11 cwts. per acre, which is half the 20 : 1 point of 2·22 and so highly significant, but it was not found possible to work out a multiple regression by this method.

2. The correlations obtained in each of the 29 chequer-board experiments between Yield and Migration, Yield and Nitrogen, Nitrogen and Migration were each transformed to 'Z', using Fisher's transformation [1]:

$$Z = \tfrac{1}{2}[\log(1+r) - \log(1-r)]$$

The three averages of Z on conversion to r give the optimum value of r between each pair of variables:

Yield	: per cent. Migration	$r = +\cdot512$
Yield	: per cent. Nitrogen	$r = -\cdot333$
per cent. Migration	: per cent. Nitrogen	$r = -\cdot379$

From these correlations we get $r = \cdot533$ and the multiple regression of Yield on per cent. Migration and per cent. Nitrogen was then calculated in the usual way. Yield$=$ $5\cdot05 + \cdot385$ per cent. M. $- \cdot303$ per cent. N.; error of prediction 1·27 cwts. per acre.

Inherited Characters in Chequer-board Experiments

One of the most useful features to know is how far the hereditary character of these factors associated with yield is overshadowed by the various cultural conditions in different years. If we compare one race with another, our main object is to get an increase in yield, but even by weighing twenty plots of each race the error in the comparative yield tends to be quite large; consequently in selecting from a large number of races for further trials it may pay to select, at any rate at first, on the basis of other features that are highly correlated with yield, but require the measurement of very many less comparisons than yield does itself to get a high figure of probability.

[1] R. A. Fisher, *Statistical Methods for Research Workers*, chap. vi.

To do this it is necessary to find out how constant the differences in hereditary characters are from year to year between the same races. Thus, for instance, in six seasons 'Plumage-Archer 1924' was compared with 'Golden Archer', and the difference in ranking between the two in each of the nine factors was averaged out for the six seasons, and the squares of these differences were added together, and, similarly, those for comparisons of other races (but never taking less than four years' comparisons); thus one got altogether a sum of 237 squares of differences for each of the nine factors, and this sum was divided by 237, and the square root extracted, thus getting S.E.s for each factor. As against this, a number of similar differences were made out at random, giving an S.E. of 2·924 (as compared with a true S.E. of 3·25, corrected for small numbers). By this method the S.E.s obtained for the various factors (as measured in ranking) were very different. The following table gives the results:

	S.E. in ranking order
Percentage migration . .	1·57
Weight of ear	1·77
No. of ears per plant . .	1·83
Weight per 1,000 corns . .	2·08
Yield	2·13
Percentage nitrogen . .	2·45
No. of corns per ear . .	2·61
Weight of whole plant . .	2·73
No. of plants per square yard .	2·83
Purely chance figure . .	2·92

These figures show very clearly that in selecting new races from the chequer-board much the easiest method of making most of the discards is by considering the migration figure, the tillering capacity, and possibly the weight of the ear, as with a new race relatively few comparisons are necessary to get significant evidence as to its value in these particulars; and it is improbable that any new race which is deficient in these particulars would have a relatively good yield.

As regards nitrogen the position is more difficult, for under the circumstances of this chequer-board comparison the S.E.

is quite high (2·45), so discarding from actual measurements is difficult. On the other hand, it is not so easy to work from other factors which have low S.E.s, thus the correlation of nitrogen with tillering is negligible but actually positive, with weight of ear and migration percentage negative but smaller and less significant than yield with these; consequently, if one chooses races for tillering capacity, weight of ear and migration, the result is much more likely to have a good yield than a low nitrogen.

It will be noticed that there is a conflict of evidence as to how far nitrogen content is a racial hereditary characteristic. In the figures given in Dr. Beaven's papers (Chapter XXX, Tables LVII, LVIII, LIX) it was certainly markedly so, but in the comparisons made by the present writer the hereditary nature appears to be insignificant. When taking out these figures it was noticed that in many of the comparisons (including those quoted in Dr. Beaven's papers) the differences were extremely constant from year to year, but in many others most erratic.

The cause of this discrepancy is not clear—possibly it is associated with the gradual elimination of high nitrogen races, so leaving differences in racial nitrogen too small for such methods of comparison. If this explanation is correct then one can make direct choice of desirable races for nitrogen as for those other factors. In actual field experiments there can be no doubt that relative nitrogen is one of the most constant characteristics when comparing different races of barley.

It is also possible to get a direct comparison for the standard error of the differences between certain races with a considerable number of years of comparison. All the cases with eight years or over were taken out and in Table D the results are given. The first thing that strikes one is the extraordinary variation in the standard errors in any individual measurements: thus, taking the first column, the standard error of the number of plants varies from 1·73 to 4·40—a ratio of 2·54—and similarly these ratios vary from 1·90 for the number of ears to 3·34 for nitrogen percentage, and the odds (assuming 8 cases in each comparison) of getting such ratios by chance are given below and are in nearly every case of the order of 1 in 100—very highly significant.

Again, this is not due to there being only extreme irregularities, for if, instead of comparing the ratio of the highest to the lowest S.E., we compare the second-highest to the second-lowest, we still get an average ratio for the nine features as high as 2·12.

On the whole it will be seen that there is a tendency for the standard errors to be high or low in the same racial comparison. Thus for each feature if we number the standard errors in order, giving 1 to the lowest and so up to 9 the highest, and then average all these figures, for each of the different comparisons we get the average order in the table varying from 1·78 for the comparison Golden Archer—'Plumage-Archer 1935' to 6·67 for 'Plumage-Archer 1924'—'Spratt-Archer 37/6'. Such differences are of course highly significant, even allowing for the fact that there is a certain amount of correlation between these various factors and so probably in their standard error.

Below in this table the actual numerical differences are given in each of these features and a similar average order was made out—in this case irrespective of sign—and here the differences are considerably less.

It was thought that it was quite possible that part of the variation in the standard error might be associated with the size of the actual differences in the same feature, as these might represent fundamental reactions to external circumstances, and there is some evidence that this is so, as on comparing in each of the features the order in the standard error with that of the actual differences we get a correlation of + ·299 for the 81 cases (but not independent ones).

One might expect that the smallest standard errors would be when races of similar parentage were compared. However it does not look as if they were associated with the type of ear; thus in the cases of both the two lowest S.E.s and the highest the comparisons are between wide and narrow, but with such a limited number of comparisons it is not possible to dogmatize.

If we compare these standard errors divided by the comparable figures of those in Table B for races it will be seen that in every case those in this table are lower than the others, ratios varying as a rule from half to three-quarters.

It will be remembered that in Table B the standard errors

were obtained by calculation from the highest and lowest figures in each column whatever the race, whilst in Table D the standard errors are made out directly from comparisons of the same pairs of races separately; consequently, one would expect the latter to have the lower figures.

It will also be noticed that, as a rule, the ratios are low with the most hereditary figures—e.g., migration, weight of ear and number of ears; whilst with the nitrogen, weight of plant and corns per ear they are more nearly unity, and are less hereditary; the only exception being the number of plants.

Correlations: 9 cases (from Table D)

Between	Actual differences	Standard errors
Yield: per cent. Nitrogen	+·034	+·547
Per cent. Migration: per cent. Nitrogen	−·824	+·417
Per cent. Migration: Yield	+·277	+·152

These correlations were made in the nine racial comparisons in Table D for the actual differences in Yield and Nitrogen, Migration and Nitrogen, and Migration and Yield. The figures for the first and last were insignificant but between Migration and Nitrogen strongly negative. The correlations of the standard error for the same features, as would be expected, were all positive, but none of them significant for so few cases.

Double Chequer-board Experiments in the Same Years

One curious feature was noticed in the ranking correlations. One would expect in those years (1914, 1921, 1928 and 1929) when the chequer-boards contained two complete series that the various correlations between one factor and another would on the whole resemble one another, but actually this was not the case, and in certain features the correlations were quite exceptional, even compared with other years; thus, for instance, the correlations between Yield and Weight of Plant were −·71 for the first set in 1914 and +·48 for the second, and again in 1929 −·76 against +·29 for the second; these

were in fact the only negative correlations in this whole series of 29 cases, while the average of them is $+\cdot53$, and in other series as well there were more exceptional correlations in these duplicated years than would be expected by chance.

Again, if we correlate together for these double years the differences that the firsts are from the average figures of that series of correlations with the similar figure for the seconds, one would expect to get on the whole a positive correlation as they were in the same season, but actually only three of the correlations are positive as against six negative, and the average of these nine correlations is $-\cdot11$, a most remarkable result.

These results are rather disturbing, and it is very difficult to see what can have been the cause of them. The method in such years was to sow all the first sets and then start on the second sets. The first sets were on the same ground as the chequer-boards in all previous years, the second sets in each of the four years followed a barley crop in the ground the season before, but before that not nearly as continuously as the first sets.

It may be that in those years there was a tendency to sow the first series rather earlier than usual and probably the second sets later compared with the weather and the conditions of the ground, and this might have had the effect of producing different growth characteristics in the two sets of plots, although it seems a very far-fetched explanation, as given good weather conditions the custom was to sow a whole series in three or four days, so if the weather continued favourable the second series would average three to four days later than the first; actually in those four seasons the first took on the average seven days to sow and the second four and a half, making the latter nearly six days behind on the average, a small difference compared with the actual variations from March 12 to April 3—three weeks—in starting to sow in these four years.

Nitrogen of Seed and Yield of subsequent Crop of Barley

It will be remembered that in direct experiments it was found that yield was positively correlated with the nitrogen

content of the seed. If we examine the annual figures for the chequer-boards we get 25 years in which we can compare nitrogen of the seed with the subsequent yield. Of course the comparison is not exact, as the barleys neither in the seed nor in the plots were identical in the two years, but on the whole they are fairly comparable and might be expected to be similar enough for this comparison, and, actually if correlated together year by year, we get correlations of +·255 for the actual and +·201 by successive differences, while a regression factor of ·1 per cent. nitrogen of seed gives ·56 and ·58 yield in cwts., per acre, respectively.

The correlations themselves are very small and not nearly significant, and so do not give very much support to the theory that high nitrogen seed gives an appreciably better yield (by giving better start to the seedling).

To see whether any further information can be obtained from the yearly averages of the Warminster figures, the nitrogen of one year is correlated with the seven other features measured in the subsequent crop, with the following results:

Correlations between per cent. nitrogen of barley of one season's crop

with subsequent	r = Actual	r = Successive differences
Number of plants	+·203	+·198
Number of ears per plant	+·098	+·070
Number of corns per ear	+·425	+·047
Weight of plant	+·093	+·054
Weight of ear	+·158	+·219
Weight per 1,000 corns	−·040	+·232
Migration coefficient	+·268	+·269
Simple average	+·172	+·156
c.f. yield	+·255	+·201

Most of the correlations are positive: the only appreciably significant one is with the number of corns per ear—'actual' $r = +\cdot425$ ($p = \cdot04$), but this is one of the features which would hardly be expected to be affected by the nitrogen content of seed, so one must regard the connection as a chance one, especially as it is not confirmed by the 'successive difference' correlation +·047. In the direct experiments in 1911 it will

be remembered the tillering was proportional to the nitrogen of the seed (and to a smaller extent to 1,000 corn weight)—1·67 stems per plant for seed of 1·79 per cent. nitrogen falling to 1·33 for seed of 1·45 per cent., the lowest of all being 1·9 for screenings of 1·40 per cent. (with equal spacing between the seeds).

In Ireland four direct experiments were made at two centres, in each case using pure Spratt-Archer 37/6 as seed, with the greatest available difference in nitrogen content from different districts in three years, but in the last year the seed came from the same district (Ballinacurra), obtaining the higher nitrogen figure by giving nitrogenous manure to the crop. The seed was sown each year in two farms in different districts (Athy, Co. Kildare, and Ballinacurra, Co. Cork) in half-acre plots. The results are given below:

Irish field experiments—4 years' average

Seed used: Nitrogen		Crop		
	Per cent.	Yield cwts. p.a.	Per cent. N.	1,000 corn wt.
High .	1·80	22·16	1·404	34·35
Low .	1·31	22·66	1·401	34·39

Actually in the first two years the yield was rather higher for the high nitrogen seed and in the other two years considerably lower. In the same two years the nitrogen of the crop from the high nitrogen seed was higher and in the later two years lower, giving exactly the same on the average. The 1,000 corn weight in the first and last years was higher for the high nitrogen seed and in the middle two years lower, again giving no average difference.

Altogether, then, under the conditions of these experiments it seems unlikely that variations of nitrogen in the seed would generally make any appreciable difference to the yield, nitrogen content, or 1,000 corn weight of the subsequent crop.

One curious fact was noticed that in the two farms the differences between the high and low nearly always went the same way, in fact in 10 out of 12 comparisons (4 years and 3 figures) the two farms went in the same direction, and only

in 2 in the opposite, and, similarly, if one correlated these differences of high minus low of one farm with the other, measuring the differences as percentages from the maximum difference in each of the three features, one got a correlation of $+\cdot 52$, which is not, of course, very significant; but certainly one would not like to dogmatize and say that under certain conditions nitrogen of seed may not be an important factor.

A further comparison can be made for Ireland; the official yield over the country of barley has been published for many years, and Messrs. Guinness have analysed their purchases from the crops for 40 seasons and these would be very similar to the seed used next year, and so it is possible to get 40 comparisons between the nitrogen of one year and the yield of the next. On the other hand, the barleys grown in the country may be divided into four periods, firstly when no standard race was grown, next Archer, then Spratt-Archer 37/6, and finally Spratt-Archer 37, No. 3—if then we compare the differences in nitrogen and yield of each season from the average of that period, we can make a correction for racial differences in these figures, and thus we get a correlation of nitrogen of seed and subsequent yield of $-\cdot 115$, or by direct successive differences $+\cdot 108$. In 1920 and 1921, however, the yields were quite abnormal (low) owing to climatic conditions, but, even if we exclude the yields of these two years, we only get correlations of $-\cdot 065$ and $+\cdot 140$, respectively.

Consequently, it seems from year to year in the chequer-boards at Warminster, in the Irish experiments, and over the whole Irish crop, that the effect of the nitrogen of seed had little or no effect on the resultant yield.

Dr. Beaven held strong views on the general question as to how far significant results of these chequer-board cage experiments could be regarded as applicable to barley-growing in the field. He pointed out that all these cage experiments were based on a purely artificial method of sowing, the seeds were spaced at $6'' \times 2''$ and the holes were punched into the ground, giving equal depths at which the seed germinated. This is quite different from agricultural practice, where twice or three times as many seeds are sown at very irregular intervals and at variable depths with friable

soil all round; and more plants are harvested, generally to the extent of 40 or 50 per cent.

It is possible that in certain years this method of sowing accentuates the influence of nitrogen content in seed on the tillering, whilst as a rule it does not; and thus we might be able to explain the difference between the direct experiments to test this question and the absence of appreciable correlations for the effects over 25 years at Warminster and also for 40 years in Ireland.

In the field two factors are involved which exist to a much smaller extent in the cage: in places the plants grow much too closely together, quite possibly a race in which many of these died off early would give a better yield than one in which they survived longer—or even to harvest. Again, while in the cage the spaces for tillering are relatively constant and small, in the field the average spacing is much closer and yet there are frequently larger areas without a plant and so the variation in tillering possibilities is very much greater.

Consequently the chequer-board method, though excellent for comparing crops that are thinned and any others that are planted out, like roots here and also rice in the East, is not really suitable for our cereals, and all the results obtained must be regarded as provisional until they have been confirmed by an agricultural method such as the half-drill strip method (see Chapter XXVII), the N.I.A.B. field experiments, or the one-acre plots in Ireland. As to whether the chequer-board or the half-drill strip method gives the more calculable, or the lower, standard error is immaterial, as what the standard errors are between the chequer-board and agricultural field methods has never been determined with a fraction of the accuracy that those of the chequer-board themselves have been. Very possibly, if one doubled or halved the sowing rate in the chequer-board, the relative order of different races of barley would change in yield as well as in many of the other factors measured—and even if they did not it still would have to be shown that more intense crowding, or even greater spacing, had no effect either.

One of the difficulties inherent in agricultural experiments lies in the fact that up to a point living organisms are self-regulating and stable, but beyond that there may be a sudden and unpredictable change. This is very well exemplified in

the records of the Irish field plots. For the twelve years 1926–37, Spratt-Archer 37, No. 3, was grown at ten different centres extending over the barley districts of Southern Ireland, and the 1,000 corn weight recorded, the yearly average varying from 31·4 to 36·2 with a standard error (11 degrees of freedom) of 1·39; from this one could predict that the odds were hundreds: 1 against a figure as low as 29·3 or as high as 39·1 and of thousands: 1 against 40·7, and yet these three averages actually occurred in the next three years.

It has been shown above from Table D that when comparing the same races of barley from year to year it is quite impossible, with chequer-board experiments, to give a representative figure for the S.E. of a comparison in any of the nine features measured. Apparently some races react in a similar manner to seasonal changes, weather, etc., and so have a small S.E. when compared. Others seem to behave much more erratically, and so have much higher standard errors in most of the features.

Table E gives the correlations for the chequer-board plots for the 25 years for reference.

Summary of Correlations and other Statistical Results

Correlations were made comparing the figures (1) for the different races in the same year and (2) the average of all the races in different years.

All the factors that together constitute yield—number of plants surviving, number of ears per plant (i.e. tillering), 1,000 corn weight (dry) and number of corns per ear—have been shown individually to be positively connected with it, but to different extents for these factors, and also as between races and seasons.

For races the most important are the number of plants surviving and the number of corns per ear and their weight; for seasons the number of ears per plant and then the number of plants surviving.

It must be remembered that many of these factors tend to be opposed: (*a*) the more the surviving plants the less the tendency to tiller ; (*b*) the more the tillers the less the weight per ear; (*c*) the more the plants, (*d*) tillers and (*e*) the corns per

ear the less one would expect the weight of each grain to be. Actually, however, only the more the tillers the less the weight per ear holds good, while racial and seasonal characteristics modify the other tendencies, so that actually more surviving plants are associated with more tillering and there are generally insignificant connections for 1,000 corn weight with number of plants and with grains per ear.

'Migration'—or the percentage that the ears are of the total plant—is a very important factor for yield as between different races, but not between seasons, and, similarly, 'migration' is negatively connected with the nitrogen content of the grain for races but insignificantly for seasons. In a favourable season, vegetative growth tends to be strong compared with seed production and to be associated with high total absorption of nitrogen from the soil.

When comparing the same races with one another in different seasons it was found that the migration coefficient, the weight of the ear and the tillering were the most constant hereditary characteristics, but, as far as these comparisons went, the nitrogen content was not nearly so much so—it is difficult to understand this, as in agricultural field experiments the nitrogen content is a very marked hereditary character.

It would appear that one cannot expect a fixed standard error for any comparison between two races—it varies very much according to what races are compared. Apparently, as might be expected, in different seasons each of one pair of races will react in a similar manner to the variations in weather, etc., whilst those of another comparison will be affected in markedly different ways from one another.

One most disturbing fact was found in four seasons, when two complete series of chequer-board plots were sown in each year the correlations obtained were very different in the two series, whilst one would expect them to be nearly identical.

The extent to which chequer-board plot barley results can be applied to normal field conditions is very difficult to assess, as tillering and plant survival are so different; consequently, however conclusive such plot results may be they should always be confirmed as soon as possible by the half-drill strip method, which is extremely close to ordinary agricultural practice.

Possibly it is some such cause that made the nitrogen content of the grain not appear to be a hereditary factor in the comparisons made by the present writer in these plots, and it may also explain how nitrogen content (and 1,000 corn weight) of seed had such an important effect on the crop in Dr. Beaven's experiments, though not from year to year, whilst it did not appear to have any in the large-scale Irish experiments, or in that country's crops.

When considering these methods of selection by growth features from which higher yielding races of barley have been chosen, we must remember that their average yields could be increased still further and yet with a high quality grain by adding soluble nitrogenous manures at or soon after sowing, except for the fact that in most seasons the crop would be badly laid. Consequently, the most important feature now to aim at is strength of straw.

G. S. PHILLPOTTS.

ST JAMES'S GATE,
DUBLIN,
July 1944.

TABLE A.—Warminster Chequer-board Plots. Twenty-five years. Factors of productivity

Year	No. of races	No. of plots	a	d	w	g	e	p	M %	n	y	y × ·08
			Avg. no. plants per sq. yd.	Avg. no. ears per plant surviving at harvest	Wt. per 1,000 corns (dry)	Approx. avg. no. corns per ear	Avg. weight per ear (grms.)	Avg. weight per plant (grms.)	$\frac{\text{Wt. ears} \times 100}{\text{Wt. plant}}$	Per cent. nitrogen dry grain	Avg. ears per sq. yd. (grms.)	Approx. cwts. grain per acre
1912	8	160	103·8	2·02	41·7	21·2	1·19	5·18	46·5	1·63	250	20·0
1913	8	160	97·3	1·94	53·3	21·8	1·57	5·78	51·4	1·51	296	23·7
1914 (avg. 2 expts.)	16	280	90·9	2·03	45·6	18·9	1·16	5·69	41·4	1·43	213	17·0
1915	8	160	104·1	1·80	44·6	19·4	1·17	5·32	39·5	1·47	220	17·6
1919	8	160	84·2	1·62	47·8	21·9	1·42	4·10	55·7	1·40	192	15·4
1920	8	115	85·6	1·89	32·1	23·5	1·03	4·10	47·0	1·95	167	13·4
1921 (avg. 2 expts.)	16	208	101·8	3·10	38·6	22·9	1·20	6·41	57·3	1·82	375	30·0
1922	8	128	102·5	2·45	32·1	21·8	·93	4·57	49·5	2·04	233	18·6
1923	8	128	98·4	1·67	43·1	24·8	1·45	4·47	54·0	1·51	238	19·0
1924	8	160	101·3	2·38	38·0	23·3	1·20	5·82	48·7	1·87	287	23·0
1925	8	160	100·2	2·12	40·0	23·4	1·27	4·78	55·8	1·49	270	21·6
1926	8	128	90·3	1·99	40·3	23·3	1·27	4·82	51·7	1·76	225	18·0
1927	6	120	94·8	1·94	32·4	20·6	·91	3·54	49·2	1·61	166	13·3
1928 (avg. 2 expts.)	14	224	100·0	2·44	43·1	23·2	1·35	6·84	48·2	1·42	332	26·6

1929 (avg. 2 expts.)	16	240	93·1	1·81	38·5	20·0	1·03	3·34	56·5	1·41	176	14·1
1930	8	160	88·6	2·86	37·8	21·2	1·10	5·81	52·8	1·52	277	22·2
1931	8	127	95·7	2·75	35·2	20·3	·97	5·65	47·4	1·70	256	20·5
1932	7	70	80·0	1·84	45·0	22·0	1·35	4·26	57·4	1·89	195	15·6
1933	8	160	102·7	2·59	39·3	21·7	1·15	5·94	50·0	1·36	305	24·4
1934	8	160	103·4	2·07	40·8	21·6	1·19	4·35	56·4	1·50	254	20·3
1936	8	145	96·5	1·76	44·3	21·2	1·27	4·31	52·1	1·58	217	17·4
1937	8	160	99·0	2·07	40·7	21·8	1·20	4·94	50·1	1·38	245	19·6
1938	8	160	103·0	2·64	41·8	21·8	1·22	5·92	54·7	1·34	334	26·7
1939	8	160	100·7	2·13	30·0	21·4	1·13	5·06	47·8	1·50	243	19·4
1940	8	160	95·4	2·18	44·7	20·2	1·22	4·87	54·4	1·48	253	20·2
Means: 25 years			96·5	2·16	40·8	21·7	1·20	5·03	51·0	1·58	249	19·9
1st $12\frac{1}{2}$ years			96·56	2·08	41·1	22·1	1·23	5·02	49·8	1·65	244	19·5
2nd $12\frac{1}{2}$,,			96·44	2·25	40·5	21·3	1·17	5·04	52·2	1·51	254	20·3
Means of correlation coefficients in each chequer-board, in each year, of *races* with *yield*, e.g. $r_{ya} = +·477$			r_{ya} +·477	r_{yd} +·299	..	r_{yg} +·267	r_{ye} +·373	r_{yp} +·529	r_{yM} +·431	r_{yn}* −·285 r_{Mn} −·287	..	

* Low *n* indicates good quality.

Note on cwts. per acre (*col.* 10) y × ·08.—Multiplying *grms. per square yard ears* by ·08 to give *cwts. grain per acre* assumes that rachis and awns weigh 16·3 per cent. of the weight of *ears*. The actual percentage is between 14 and 18 per cent. Also, the ears are weighed with about 12·0 per cent. moisture, whilst the average moisture of English crops is about 15–16 per cent. Cwts. per acre shown on above table are therefore on the low side.—E. S. B.

see key below)

(7) tal weight of plant		(8) Wt. of ears × 100 / Total wt. of plant = % Migration		(9) Per cent. nitrogen		(10) Yield	
18 92	(·2) +·420	+·181 −·172	(·05) −·374	−·094 −·185	(·3) −·294	+·477 +·592	(·000) +·525
98 92	(·001) +·800	−·109 +·079	(·2) −·185	+·114 +·176	(·2) −·073	+·299 +·744	(·004) +·813
04	+·791	+·020	−·242	+·105	−·140	+·817	+·828
59 246	(·07) +·220	+·323 +·092	(·000) +·625	−·033 −·489	(·3) −·334	+·263 +·198	(·031) +·320
281 068	(·003) +·320	+·273 +·439	(·021) +·296	−·321 +·337	(·004) −·116	+·267 +·231	(·001) +·335
291 231	(·000) +·290	+·469 +·341	(·000) +·570	−·257 +·326	(·031) −·300	+·373 +·262	(·004) +·365
1 1	1	−·085 −·230	(·3) −·225	−·067 −·103	(·2) −·135	+·529 +·856	(·000) +·905
·085 ·230	(·3) −·225	1 1	1	−·287 −·011	(·003) −·281	+·431 +·188	(·000) +·075
P·067 103	(·2) −·135	−·287 −·001	(·003) −·281	1 1	1	−·285 −·112	(·001) −·286
Y·529 856	(·000) +·905	+·431 +·188	(·000) +·075	−·285 −·112	(·001) −·286	1 1	1
St·369 841	grms. 1·54	1·86 4·67	per cent. 6·98	·086 ·190	·290	1·62 4·11	cwts. 7·25
St·44	1·83	·40	1·50	·45	1·53	·39	1·76
5·03 5·025 5·045		51·0 49·85 52·19		1·58 1·654 1·510		19·9 19·51 20·29	

year in chequer-board.
: averaged in I.

es year to year, 24 cases.

Yearly comparisons

No. of cases	P =	·05	·01
		r	
25 24	Actual S. diffs.	·403 ·468	·512 ·590

f difference

ht t	Per cent. migration	Per cent. nitrogen	Yield cwts. per acre	Average order 1 = lowest 9 = highest
Pl. Archer 195	2·315	·1290	2·63	6·67
4	1·256	·1417	1·61	6·56
,, ,, 9	1·215	·1005	2·19	5·78
,, ,, 9	0·823	·0424	1·07	2·11
,, ,, 2	1·159	·0688	1·47	3·78
,, ,, 4	2·080	·0658	1·13	1·89
Eng. Archer, 8	·756	·0725	2·74	5·67
,, ,, 0	·848	·0655	1·50	2·78
,, ,, Golden Arche3	·952	·0557	1·09	1·78
15	1·462	·0913	1·876	
8	1·034	·0640	1·326	
	3·05	3·34	2·52	
	< ·01	< ·01	> ·01	
9	1·86	·086	1·6	
	·55	·75	·82	

ices

ht t s.	Per cent. migration	Per cent. nitrogen	Yield cwts. per acre	Average order irrespective of sign 1 = lowest 9 = highest
Pl. Archer 194	+3·50	−·198	− ·588	4·33
8	+2·15	−·136	+1·550	6·00
,, ,, 1	+1·38	−·086	− ·254	2·78
,, ,, 3	−1·75	+·004	−1·186	2·33
,, ,, 1	−1·13	−·098	− ·976	3·00
,, ,, Eng. Archer, 0	−1·86	+·040	−1·052	3·78
9	+ ·03	+·053	+2·827	5·44
,, ,, 9	+ ·78	−·050	+1·802	4·67
,, ,, Golden Arch5	−3·06	+·031	− ·887	3·78

E.–

ı- .	% itro- zen	Per cent. N. of grain with: 1,000 corn weight	No. corns per ear	Weight whole plant	1,000 corn weight with: No. corns per ear	Weight whole plant	Corns per ear with: Weight whole plant
l	-·26	+·46	−·70	−·10	−·49	+·10	−·36
)	-·12	−·08	−·19	−·34	+·08	+·01	−·12
2	-·48	−·71	+·65	+·19	−·80	−·05	+·29
4	-·65	+·20	−·02	± 0	−·11	+·56	+·40
3	-·46	−·57	−·88	−·57	+·64	+·48	+·36
6	-·35	−·28	−·32	+·66	+·10	−·52	+·19
4	: 0	−·02	−·40	+·02	+·24	+·95	+·29
6	-·53	−·13	+·37	+·40	+·44	+·56	+·86
4	-·34	−·06	−·81	−·48	+·11	−·43	± 0
5	-·02	+·36	−·67	−·24	−·17	+·26	+·26
1	-·33	+·72	−·08	+·10	−·02	+·38	+·55
7	-·33	−·48	−·08	−·77	+·42	+·10	+·43
8	-·26	+·51	−·02	+·66	+·38	+·31	+·11
5	-·40	+·07	+·20	+·31	± 0	−·08	+·67
9	-1·00	+·59	−·43	+·26	−·90	−·12	−·03
9	-·56	+·07	−·45	−·58	−·21	−·14	+·96
7	-·21	+·14	+·22	−·18	+·33	−·97	−·41
9	-·24	+·48	+·19	+·62	+·47	+·13	+·02
	-·88	−·08	−·81	−·12	+·25	+·36	+·29
8	-·04	+·81	+·07	+·23	+·33	+·19	+·74
0	-·45	−·43	−·86	−·07	+·38	+·69	+·05
9	-·41	+·17	−·63	+·04	−·61	−·23	+·07
2	-·38	+·06	−·96	−·60	−·22	−·01	+·74
1	-·22	−·26	−·66	−·16	+·10	+·24	+·62
5	-·67	−·34	+·22	−·17	−·74	+·53	−·20
9	-·21	−·31	−·36	−·38	+·38	+·29	−·19
2	-·68	−·54	−·81	−·17	+·04	−·29	+·36
8	-·26	−·83	−·47	−·33	+·59	+·40	+·60
1	-·02	−·48	−·63	−·18	+·74	+·90	+·60
'81	-·287	−·033	−·321	−·067	+·060	+·159	+·281
½	6½	13	7	11½	18½	19	22½
½	22½	16	22	17½	10½	10	6½
5	·003	·3	·004	·2	·10	·07	·003

APPENDICES

APPENDIX A.—VARIETIES OF BARLEY

H. *Sativum*. Natural Varieties

Hordeum hexastichum.

Spikes normal.[1]
Var. *brachyatherum*, Kcke.
Awns very short.
pyramidatum, Kcke.
Spike pyramidal.
parallelum, Kcke.
Spike parallel.
Schimperianum, Kcke.
Spike black.
Spikes abnormal.
Var. *recens*, Kcke.
Glumes long, ovate-lanceolate, with short awns.
GRAIN NAKED.
Spike normal.
Var. *revelatum*. Kcke.

Hordeum vulgare.

Spikes normal.
Var. *pallidum*, Al.
Normal form.
coerulescens, Al.
Grain grey-blue.
nigrum, Willd.
Paleae and grain blackish.
leiorrhynchum, Kcke.
Paleae and grain black, awns smooth.
Spikes abnormal.
Var. *Horsfordianum*, Wittm.
Paleae trifurcate.
crispum, Kcke.
Spike branched.
GRAIN NAKED.
Spikes normal.
Var. *coeleste*, L.
Normal form.
himalayense, Rittig.
Grain violet.
Walpersii, Kcke.
Grain bluish grey.
violaceum, Kcke.
Paleae dark.
Grain violet.

Hordeum vulgare—*continued.*

Spikes abnormal.
Var. *cornutum*, Schrad.
Median paleae trifurcate, lateral short-awned.
trifurcatum, Schl.
Paleae trifurcate.

Hordeum intermedium.

Spikes normal.
Var. *transiens*, Kcke.
Spike wide.
Haxtoni, Kcke.
Spike narrow.

Hordeum zeocriton, L.

Spikes normal.
Var. *zeocrithum*, L.
Spike converging.
erectum, Schubl.
Spike parallel.
melanocrithum, Kcke.
Spike black.
Spikes abnormal.
Var. *heterolepis*, Kcke.
Spike parallel.
Lateral glumes broad, lanceolate.
GRAIN NAKED.
Spikes normal.
Var. *Rossii*, Kcke.
Spike parallel.
Grain blue-grey.

Hordeum distichum.

Spikes normal.
Var. *nutans*, Schubl.
Normal form.
medicum, Kcke.
Grain grey-blue, awns smooth.
Atterbergii, Kcke.
Lateral spikelets large.
nigrescens, Kcke.
Spike blackish.

[1] i.e. the rachis simple (not branched); the outer palea awned; the glumes narrow, spike-shaped, shorter than the grain and not awned. See Figs. 12, 13.

Hordeum distichum—*continued.*

Var. *persicum*, Kcke.
Spike brown.
Awns smooth.
nigricans, Al.
Spike black.
Spikes abnormal.
Var. *Braunii*, Kcke.
Glumes ovate-lanceolate, projecting, and awned.
Rehmii, Kcke.
Glumes lanceolate, projecting, and long-awned.

Grain Naked.
Spikes normal.
Var. *nudum*, L.
Normal form.
Spikes abnormal.
Var. *compositum*, Kcke.
Spike branched.

Hordeum decipiens.

Spikes normal.
Var. *deficiens*, Steudel.
Normal form.
Var. *Seringei*, Kcke.
Spike brown.
Steudelii, Kcke.
Spike black.
Spikes abnormal.
Var. *abyssinicum*, Ser.
Glumes narrow, lanceolate, with short projecting awns.
macrolepis, A. Br.
Glumes lanceolate.
Paleae black.

H. *Sativum.* Hybrid Varieties

Hordeum hexastichum.

Spikes abnormal.
Var. *eurylepis*, Kcke.
Glumes long, ovate-lanceolate, with long awns.
platylepis, Kcke.
Spike black.
Glumes long, ovate-lanceolate, with long awns.
hexastico trifurcatum, K.H.
Awns short.
Trifurcate appendage.
hexastico furcatum, K.H.
Palea trifurcate.
densifurcatum, K.H.
Spike black.
Glumes lanceolate.
Palea trifurcate.
complanatum, K.H.
No awns.
Palea of median florets only trifurcate.
thyrsoideum, K.H.
Spikelets very crowded.
hexastico ramosum, K.H.
Spike branching.

Grain Naked.
Spike normal.
Var. *nudipyramidatum*, Kcke.
Normal form.
nudiprysmaticum, K.H.
All spikelets diminutive.
abiens, K.H.
Lateral spikelets diminutive.

Hordeum vulgare.

Spike normal.
Var. *subviolaceum*.
Paleæ and grain violet.
Spikes abnormal.
Var. *atrum*, Kcke. (1).
Paleae and grain black, trifurcate.
latiglumatum, Kcke.
Glumes ovate-lanceolate and awned.
atrospicatum, Kcke.
Glumes lanceolate and awned, black paleae.
elongatum, K.H.
Paleae trifurcate.
hamulatum, K.H.
Awns short.
Paleae trifurcate.
laxifurcatum, K.H.
Paleae trifurcate, black.
refractum, K.H.
Paleae trifurcate.
atroides, K.H.
Paleae and grain black, trifurcate.
versifurcatum, K.H.
Median paleae trifurcate, lateral awnless or subtrifurcate.
longihamatum, K.H.
Paleae trifurcate.
mutilatum, K.H.
Lateral spikelets diminutive and short-awned.
Spike black.
Grains violet.

Hordeum vulgare—*continued.*

GRAIN NAKED.
Spikes normal.
Var. *duplonigrum*, Kcke (1).
Paleae black.
Grain black.
Spikes abnormal.
Var. *nudimutilatum*, K.H.
Lateral palea short-awned and irregular.
aethiops, Kcke. (1).
Paleae black.
Grain black.
Paleae trifurcate.
nudiramosum, K.H.
Spike branched.

Hordeum zeocriton, L.

Spike normal.
Var. *erecto zeocriton*, K.H.
Normal form.
melanozeocriton, K.H.
Paleae black.
Awns and glumes white.
Spikes abnormal.
Var. *macrolysis*, K.H.
Spike parallel.
Glumes broad, lanceolate, and awned.
mixtum, K.H.
Spike black.
Glumes broad, lanceolate, and awned.
Neilsenii, K.H.
Spike black.
Glumes median and lateral awned.
furcato zeocriton, K.H.
Paleae trifurcate.
latispicatum, Kcke. (1).
Spike parallel.
Paleae trifurcate.
GRAIN NAKED.
Spikes normal.
Var. *gymnocrithum*, Kcke. (2).
Spike converging.
erecto nudum, K.H.
Spike parallel.
neogenes, Kcke. (2).
densum, Kcke. (1).
Spike parallel.
Paleae trifurcate.

Hordeum distichum.

Spikes normal.
Var. *rigens*, K.H.
Smooth awns.
violascens, K.H.
Grain blue-grey.

Hordeum distichum—*continued.*

Var. *glabrum*, K.H.
Smooth awns.
canescens, K.H.
Grain blue-grey.
hypianthium, Kcke.
Spike violet.
pictum, K.H.
Paleae of median row black, lateral yellow.
Spikes abnormal.
Var. *parvihamatum*, K.H.
Awns short and trifurcate.
Körnickei, K.H.
Glumes lanceolate.
Grain violet.
eingens, K.H.
Glumes narrow, lanceolate. Paleae black.
angustispicatum, Kcke. (1).
Paleae trifurcate.
hybridum, K.H.
Paleae trifurcate, lateral paleae large.
Rimpani, Wittm. (1).
Paleae trifurcate. Black.
inerme, Kcke. (1).
Awnless.
nigrosubinerme, K.H.
Awns very short. Black.
decussatum, Kcke. (1).
Awnless. Black.
GRAIN NAKED.
Spike normal.
Var. *ramulosum*, K.H.
Spike branched.
ianthinium, Kcke.
Paleae blackish.
Grain violet.
Spikes abnormal.
laxum, Kcke. (1).
Paleae trifurcate.
utriculatum, K.H.
Paleae trifurcate, hooded.

Hordeum decipiens.

Spikes normal.
Var. *sub-glabrum*, K.H.
Spike black. Awns smooth.
atratum, K.H.
Spike loose. Black.
violascens, K.H.
Paleae brown.
Spikes abnormal.
Var. *furcato macrolepis*, K.H.
Glumes lanceolate.
Black.
Paleae trifurcate.

Hordeum decipiens—*continued.*

Var. *triceros*, Kcke. (1).
Paleae trifurcate.
tridax, Kcke. (1).
Paleae trifurcate. Black.
subinerme, Kcke. (1).
Awnless.
subdecussatum, Kcke. (1).
Awnless, black.

GRAIN NAKED.
Spikes normal.
Var. *nudideficiens*, Kcke. (1).
Normal form.
vivescens, K.H.
Grain violet.
decorticatum, Kcke. (1).
Grain black.

Hordeum decipiens—*continued.*

Spikes abnormal.
Var. *monstrosum*, K.H.
Paleae trifurcate.
Grain black.
serratum, K.H.
Paleae trifurcate.
leucocarpum, K.H.
Paleae trifurcate.
gymnospermum, Kcke. (1).
Paleae trifurcate and black.
Grain black.
duploalbum, Kcke. (1).
Awnless.
duploatrum, Kcke. (1).
Awnless.
Paleae black.

NOTES ON NATURAL VARIETIES.—*Hordeum hexastichum.* Var. *brachyatherum* is a native of Japan, *Schimperianum* and *revelatum* of Abyssinia. The distinction between *pyramidatum* and *parallellum* is in my experience of doubtful constancy. These latter are the common forms of *hexastichum.*

Hordeum vulgare. Var. *pallidum* is the common form; *coerulescens* is a doubtful variety. Grain with blue-grey colouring matter in the aleurone layer is common in all barleys, both two-rowed and six-rowed, grown in hot climates, and in my experience is of doubtful constancy when the habitat is changed. Var. *nigrum* is common in the East. All black varieties seem to be natives of hot climates. *Horsfordianum* is rare. It is the parallel form of *trifurcatum*, but with adhering paleae. *Coeleste* is the common form of naked six-rowed barley, and *himalayense* is the Himalayan variety (with black seed). The naked, awnless, trifurcate variety *trifurcatum* (known as Nepaul barley, sometimes as Nepaul wheat) is also cultivated. Var. *cornutum* is said by Körnicke to be grown in South Africa, and is intermediate between *coeleste* and *trifurcatum.*

Hordeum intermedium. Both these varieties are of doubtful constancy.

Hordeum zeocriton. Vars. *melanocrithum* and *Rossii* are Abyssinian forms.

Hordeum distichum, var. *nutans*, is the common narrow-eared barley. The black forms, also those with smooth awns, are common in the East, and in Mediterranean barleys.

Hordeum decipiens. All natural varieties of this group are Abyssinian forms. It would appear, indeed, that there are more distinct varieties of barley in Abyssinia than in any other part of the world.

HYBRID VARIETIES.—Var. *eurylepis.* In *Die Saatgerste* this is described as an Abyssinian variety, but in a later publication (*Die hauptsächlichsten Formen der Saatgerste*, Bonn, 1895) Körnicke

describes both it and *platylepis* as the progeny of a cross between H. *hexastichum* and var. *macrolepis* by Dr. Beyerinck, of Delft. The same crossing also gave vars. *latiglumatum* and *atrospicatum*. I obtained specimens of hybrids listed above from Mr. Karl Hansen, of Lyngby. Those named by Körnicke (Kcke.) are described in his publication of 1895 above referred to. Those with the affix K.H. are, I believe, results of crosses by Mr. Hansen, but I have no information of their parentage. A large number of these hybrids were originated by Rimpau by crossing the very widely different varieties H. *vulgare*, var. *trifurcatum* (Nepaul naked barley), with *Steudelii*, the black Abyssinian two-rowed barley (with rudimentary lateral spikelets), which I have classed under H. *decipiens*, and are those marked (1) in the above list. Hybrids marked (2) were also obtained by Rimpau by crossing vars. *trifurcatum* and *zeocrithum*.

I have satisfied myself of the constancy of the above forms as far as possible by cultivating them and comparing them with the descriptions of Körnicke and with the original spikes received from Mr. Hansen. On the subject of cross-fertilization compare Rimpau, *Landw. Jahrb.*, 20, 1891, p. 239, with Bateson's account of Mendel's work (in 1865), *Journ. R.H.S.*, 26, 1901.

APPENDIX B.—BARLEY COLLECTION[1]

Amongst barleys still in cultivation in the nursery at Warminster are the following:

(1) *Russian Barleys*

These barleys have been continuously grown from 70 ears received from the British Embassy at St. Petersburg in 1903. These ears were stated to represent the varieties grown in various provinces of Russia at that time.

They are mainly either narrow-eared two-rowed barley of the same types as are grown all over Europe (viz., H. *distichum*) or six-rowed barley of H. *vulgare* type. Wide-eared two-rowed (H. *zeocritum*) and wide-eared six-rowed barley (H. *hexastichum*) rarely occur in Russia.

The following list shows the provinces of Russia where the original ears of barley were grown in 1900:

v = H. *vulgare*. *d* = H. *distichum*

R.12.	Saratof.	*v*	
R.13.	Do.	*d*	
R.15.	Mohilev.	*d*	
R.16.	Kherson.	*d*	
R.17.	Don.	*d*	
R.18.	Orlov.	*d*	Late ripening.
R.21.	Uia.	*d*	
R.22.		*d*	
R.49.	Kovno.	*d*	
R.51.	Erivan.	*d*	
R.52.	Volhynia.	*d*	
R.54.	Don.	*d*	
R.55.	Don.	*d*	
R.62.	Archangel.	*v*	
R.67.	Kostroma.	*v*	
R.70.	Kief.	*d*	Late ripening.
R.73.	Ural.	*d*	Do.
R.74*a*.	Don.	*d*	
R.74*c*.	Don. *hexastichum*.		Prostrate winter habit.
R.76.		*v*	
R.89*a*.	Don.	*v*	
R.89*b*.	Don.	*v*	
R.96.	Kharkov.	*d*	Late ripening.
R.99.	Bessarabia.	*v*	Semi-prostrate habit.
R.100.	Do.	*d*	Do. do.
R.100c.	Do.	*v*	Do. do.
R.127*a*.	Kostroma.	*d*	Do. do.
R.127*b*.	Do.	*v*	Do. do.
R.130*a*.	Poltava.	*v*	Do. do.
R.130*b*.	Do.	*d*	Do. do.
R.133.	Do.	*d*	
R.144.	Kusk.	*d*	Do. do.

R.149.	Tiflis.	*d*	
R.150.	Erivan.	*d*	
R.163.	Kars.	*d*	
R.172.	Tiflis.	*d*	
R.179.	Erivan.	*d*	
R.188.	Kars.	*d*	
R.189.	Tiflis.	*d*	
R.190*a*.	Erivan.	*d*	
R.190*b*.	Erivan.	*d*	Splitting. Query, natural hybrid.
R.194.		*d*	Early ripening.
R.233.	Kuban.	*d*	Late ripening.
R.234.	Do.	*d*	Very late ripening.
R.246.	Kars.	*d*	
R.246(1).	Do.	*d*	
R.250.	Erivan.	*d*	
R.254.	Stavropol.	*d*	
R.256*a*.	Kars.	*v*	
R.256*b*.	Do.	*d*	Semi-wide ear, naked grain.
R.261.	Daghestan.	*d*	Do. do.
R.266.	Kars.	*d*	Semi-wide.
R.267.	Erivan.	*d*	
R.269.	Do.	*d*	Late ripening.
R.271.		*d*	
R.276.		*d*	Very vigorous.
R.277.	Akmolinsk.	*d*	
R.279.	Iletzk.	*d*	
R.279*a*.	Do.	*v*	
R.287.	Kherson.	*d*	
R.288.	Do.	*d*	
R.293.	Petersburg.	*d*	

[1] In the case of ears to which I can attach a country of origin the seed came to me in all cases in commercial bulk from the countries named, but I

(2) *Hansen Collection*

In 1900 about 300 ears of barley (all botanically named) were received from Mr. Karl Hansen of Lyngby, Denmark.

The present collection of 180 varieties includes:

(*a*) Nearly all the *natural* varieties grown in any part of the world.

(*b*) A number of hybrids originated for the most part either by Herr Rimpau of Schlanstedt (Saxony), one of the early grain hybridizers, or by Mr. Hansen himself. Hansen's original names and numbers are retained.

N. signifies natural variety. Most of these varieties are in cultivation, frequently mixed together, in some part of the world.

H. signifies a hybrid race. Nearly all these have originated from artificial cross-fertilizfition. Their botanical names were given to them by their originators and the number has rapidly increased since they were classified by the writer in 1902. There appears to be no object in continuing the practice of giving botanical names to such artificial hybrids as are unlikely to survive except in nursery collections. The subject of the botanical classification of barley is, moreover, at present in a hopeless state of confusion. All the sub-species of barley cross-fertilize readily. Many hybrids are intermediate between different sub-species, and cannot be assigned to either—and few, if any, are constant in *all* their characters. Even a satisfactory system of nomenclature for races of barley has yet to be evolved.

am sure that in many cases the seed came originally from other countries. I think that only in a few cases (e.g. perhaps Abyssinia) can we be fairly sure that we know the country in which a variety originated.

[Table

Hansen's No.	Sub-species	Variety	Common name	N. = Natural H. = Hybrid	Locality, etc.
1	*Hexastichum*	*platylepis*	..	H.	
10	Do.	*Schimperianum*	Black, 6-row wide	N.	Occurs in Syrian barley.
16	Do.	*pyramidatum*	6-row wide	N.	Syria and on the Pacific Coast.
19	Do.	do.	6-row wide	N.	
29	Do.	*nudiptramidatum*	..	H.	
33	..	..	..	H.	
36	*Vulgare*	*latiglumatum*	..	H.	
38*a*	*Hexastichum*	*eurylepis*	..	H.	
38*b*	..	..	..	H.	
40	Do.	*recens*	..	N.	Occurs occasionally in 6-row wide-eared barley.
42	*Vulgare*	*leiorrhynchum*	Black, smooth awns	N.	Do. in 6-row narrow.
53	Do.	*nigrum*	Black, 6-row narrow	N.	Mesopotamia, Syria, Persia.
57	Do.	*coerulescens*	Blue grain, 6-row narrow	N.	Spain and California, widely distributed.
74*b*	Do.	*pallidum*	Common narrow 6-row 'Bere'	N.	In all barley-growing countries.
82–2	Do.	do.	..	N.	
85	Do.	*duplonigrum*	Naked black, 6-row	H.	
93	Do.	*violaceum*	..	N.	Sweden, France, Germany (rare).
105*a*	Splitting—	possibly a natural	Hybrid.		
105*b*2					
114	*Vulgare*	*coeleste*	Common naked, 6-row	N.	Japan — also in Europe, but small areas only cultivated.
116	Do.	*elongatum*	..	H.	
119	Do.	*atroides*	..	H.	
121	Do.	*aethiops*	..	H.	
123	Do.	*horsfordianum*	Hooded, 6-row	N.	
123*a*	Do.	Splitting form of above	..	..	Probably 123 is a natural Hybrid.
127	Do.	*trifurcatum*	Nepaul Wheat	N.	Nepaul, Tibet, Himalayas, Rhodesia, U.S.A.
132	Do.	*refractum*	..	H.	
132*a*	..	Splitting forms	..	H.	
132*a*1				H.	
132*b*				H.	
135	*Vulgare*	*mutilatum*	..	H.	
143	Do.	*sub-violaceum*	..	H.	
149*a*1	..	Splitting forms	..	H.	
149*a*2				H.	
149*b*				H.	
149*c*				H.	

Hansen's No.	Sub-species	Variety	Common name	N. = Natural H. = Hybrid	Locality, etc.
150	*Zeocrithum*	..	Fan Barley	N.	Europe, but now rare.
150*ca*	*Hexastichum*	..	..	N.	
150*cb*	Do.	..	..	N.	
156	*Vulgare*	*pallidum*	..	N.	
160	*Intermedium*	*transiens*	..	H.	
161	Do.	*Haxtoni*	..	H.	
165	Do.	do.	..	H.	
166*b*1	..	..	..	H.	
166*b*2	..	..	..	H.	
166*c*	..	..	..	H.	
170*a*	..	..	..	H.	
170*b*	..	..	..	H.	
175	*Distichum*	*Rimpaui*	..	H.	
177	*Zeocrithum*	*latispicatum*	..	H.	
181	*Distichum*	*augustispicatum*	..	H.	
181*b*	..	..	..	H.	
185	..	*utriculatum*	..	H.	
188	..	*laxum*	..	H.	
189	*Decipiens*	*tridax*	..	H.	
192	Do.	*triceros*	..	H.	
193	Do.	*monstrosum*	..	H.	
196	Do.	*gymnospermum*	..	H.	
200	Do.	*triceros*	..	H.	
211	*Distichum*	*inerme*	..	H.	True awnless.
221	Do.	*Rehmii*	..	N.	
230	*Zeocrithum*	*Neilsenii*	..	H.	
230*a*	Do.	..	..	H.	
233	*Distichum*	*Körnickei*	..	H.	
234	Do.	*eingens*	..	H.	
235	Do.	*Braunii*	..	N.	
236	Do.	..	..	H.	
240	*Decipiens*	*macrolepis*	..	N.	Abyssinia.
240*b*	..	..	..	N.	
246–2	..	*abyssinicum*	..	N.	Do.
250	..	..	..	H.	Do.
251	..	..	..	H.	
262*a*	..	*ianthinium*	..	H.	
262*b*					
262*c*	..	..	..	H.	
266	*Distichum*	*nudum*	Naked, 2-row	N.	Most parts of Europe, small areas.
268	..	..	..	H.	Common in Eastern Asia.
275	*Distichum*	*persicum*	*Black*	N.	
278	*Zeocrithum*	*melanozeocriton*	..	H.	
280	..	..	..	H.	
288	..	..	..	H.	
290	*Distichum*	*nigrescens*	Black	N.	Common in Eastern Asia.
291*a*	..	..	..	H.	
291*ab*	..	..	..	H.	

Hansen's No.	Sub-species	Variety	Common name	N. = Natural H. = Hybrid	Locality, etc
296	*Distichum*	*nigricans*	Black, 2-row	N.	Common Eastern Asi
300					
309	Do.	*violascens*	..	H.	
313	Do.	*canescens*	..	H.	
313*b*					
319	*Decipiens*	*Steudelii*	..	N.	Abyssinia.
321	Do.	do.	..	N.	Do.
322	Do.	*Seringei*	..	N.	Do.
327	Do.	*atratum*	..	H.	
334	..	..	..	N.	Splitting Natu Hybrid.
339	*Distichum*	..	..	N.	
343	Do.	*erectum*	Plumage	N.	Sweden, Engla
353	Do.	*nutans*	..	N.	
358	Do.	..	..	N.	
362–1	Do.	..	..	N.	
362–2	Do.	..	..	N.	
366	Do.	*erectum*	..	H.	
373	Do.	*rigens*	..	H.	
376	Do.	*Atterbergii*	..	N.	Rare.
378	Do.	*nutans*	Archer type	..	Europe, Ameri Australia.
383	Do.	*glabrum*	Smooth awns	H.	
390, 395, 397	*Distichum*	*nutans*	Chevalier	N.	World-wi many differ races.
410, 411	*Decipiens*	*deficiens*	..	N.	Abyssinia.
417	*Distichum*	..	..	H.	
418	..	..	..	H.	
421	*Distichum*	*nudi ramulosum*	..	H.	
421*b*	..	..	..	H.	
448	..	..	..	H.	
451	..	..	..	H.	
456	*Zeocrithum*	..	..	N.	
459	*Distichum*	*latispicatum*	..	H.	
462*a*	..	..	..	H.	
462*b*	*Distichum*	*parvihamatum*	..	H.	
463*a*	Do.	do.	..	H.	
463*b*	..	..	..	H.	
464	*Zeocrithum*	*furcozeochrithum*	..	H.	
470	*Distichum*	*augustispicatum*	..	H.	
474	*Vulgare*	*versifurcatum*	..	H.	
484	..	..	..	H.	
489, 489*a*	Splitting	..	..	H.	
490*a*	..	..	..	H.	
490*b*	..	..	..	H.	
499	*Distichum*	*augustispicatum*	..	H.	Splitting 1924.
500	..	..	..	H.	
505	..	*setosum*	..	H.	
513	..	..	..	H.	

Hansen's No.	Sub-species	Variety	Common name	N. = Natural H. = Hybrid	Locality, etc.
521	*Zeocrithum*	*erecto zeocrithum*	..	H.	
528	Do.	*nutans*	..	H.	
532	..	*erecto nudum*			
534	..	Do.	..	H.	
538	..	..	..	H.	
539	..	..	..	H.	
540	..	..	..	H.	
552	..	..	..	H.	
554	..	..	..	H.	
559	*Decipiens*	*tridax*	..	H.	
559*a*	..	..	..	H.	
560	..	..	..	H.	
563	*Vulgare*	*hamulatum*	..	H.	
566	..	..	..	H.	
568	..	..	..	H.	
570	..	..	..	H.	
575	*Distichum*	*nigrosubinerme*	..	H.	
578	*Hexastichum*	*hexastico ramosum*	..	H.	
590*a*	..	..	..	H.	
590*b*	..	..	..	H.	
591	..	..	..	H.	

No. 343 of this collection (a natural variety) is the parent culture of the race now known as 'Plumage'.

Plumage is one of the parents of all the various hybrid 'Plumage-Archers' which have been raised at Warminster.

Hansen's No. 584 (not included in this list) is H. *hexastichum* var. *thyrsoideum*. It is a sport, or 'mutation', which occurred amongst some hybrids raised by Hansen some time before 1900. It remained true to type in the nursery up to 1925, when it commenced splitting out into various types, possibly in consequence of cross-fertilization by wind-borne pollen from another variety.

Numerous hybrids have been raised at Warminster from Hansen's barleys, but only the 'Plumage-Archers' have so far proved to be of agricultural value.

(3) *Körnicke Collection*

These barleys have been grown continuously since 1902 from a collection of ears sent by Professor Friedrich Körnicke, of the University of Bonn. They represent various varieties described in his standard botanical work, *Handbuch des Getreidebaues* (*Handbook of the Cereals*), Berlin, 1885.

[TABLE

No.	Sub-species	Variety	N. = Natural H. = Hybrid	Locality in which cultivated
K. 1	H. *hexastichum*	*brachyatherum*	N.	Japan.
2	Do.	*japonicum*	N.	Japan.
3	H. *vulgare*	*violaceum*	N.	
4	Do.	*coeleste*	N.	France, Belgium.
6	Do.	*dulpo nigrum*	H.	
7	Do.	*nigrum*	N.	E. Asia.
8	Do.	*Walspersii*	N.	Spain.
9	Do.	*himalayense*	N.	N. India.
10	Do.	*nigrum*	N.	Persia—Irak.
11	H. *intermedium*	*transiens*	N.	
14	H. *distichum*	*nutans*	N.	World wide.
15	Do.	*Rehmii*	N.	
16	H. *vulgare*	*persicum*	N.	Persia.
18	H. *distichum*	*nigricans*	N.	Abyssinia.
19	Do.	*ianthinum*	H.	
21	Do.	*erectum*	N.	Europe.
22	H. *intermedium*	*Haxtoni*	N.	
25	H. *decipiens*	*deficiens*	N.	Abyssinia.
26	H. *distichum*	*nudum*	N.	France, etc.
27	H. *zeocrithum*	..	N.	Europe (now rare).
29	H. *distichum*	*Braunii*	N.	

(4) *Danish Collection*

Each culture is the progeny of one of 50 ears (each of a different-named race) received in 1900 from Mr. Chr. Sonne, Director of the Barley Experiments of the Royal Agricultural Society of Denmark, and represent 36 of the races tested for yield at four different stations in Denmark continuously between 1880 and 1900, with four replications, each year, at each station.

D.1. Prenticebyg (Danish Archer) Skanska selection.
D.2. Do. do. Copenhagen selection.
D.3. Do. do. Swedish (Svalof) selection.
D.5. Do. do. Danish (Lyngby) selection.
D.6. Chevalier. Swedish (Svalof) selection.
D.7. Prenticebyg (Danish Archer) Danish selection.
D.8. Chevalier. Danish selection.
D.9. Jarman's Chevalier.
D.10. Hallett's Chevalier.
D.11. Webb's Kinver Chevalier.
D.12. Steensgaard (Danish) Chevalier.
D.13. Lyngelbakgaard—Danish wide ear.
D.14*b*. Alsace Chevalier.
D.16. Wrinch's Chevalier.
D.17. Webb's Golden Grain Chevalier.
D.18. Webb's New Universal Chevalier.
D.19. Heines' (German) Chevalier.
D.20. Heines' (German) 'Goldfoil'.
D.21. Golden Drop (Old English Chevalier).
D.22. Webb's Golden Melon (Chevalier).

D.23.	Holstein Chevalier.
D.24.	Montana (American) Chevalier.
D.25.	Glorup. German Archer type.
D.26.	Duvelbyg. Danish Archer.
D.28.	Webb's Burton Malting. Goldthorpe type.
D.29.	Bestchorne's Kaiserbyg. German Goldthorpe.
D.29*b*.	Do. do.
D.30*a*.	Webb's Beardless.
D.30*c*2.	Do.
D.31.	Garton's Goldthorpe.
D.32.	Do. Standwell.
D.33*b*.	Fredricksens Krysenbyg.
D.34.	Swedish (Svalof) Svanhalsbyg. (Swan neck.) Goldthorpe type hybrid.
D.35.	Danish 6-row.
D.37*b*.	Do.
D.49.	Do.

(5) *Imported Commercial Varieties*

These consist of cultures all of which have originated from single selected plants grown from grain taken from foreign commercial samples collected between 1896 and 1935. They include specimens of practically all the forms in cultivation in those countries from which barley is imported into this country.

These cultures, like those of the Russian varieties, illustrate the fact that the *quality* of the grain as exported to this country is far more dependent on climate than on race. For instance, the appearance of the grain of F.9 and of F.34 when grown as here under similar conditions is indistinguishable, and in both cases quite unlike the grain as grown in their native habitats.

A few of these commercial varieties have now been discarded.

F.7.	Smyrna, 1901.
F.9.	Do. 1901.
F.11.	Do.
F.12*a*.	Smyrna, 1899, 6-row, smooth awns.
F.14.	Danubian, 1901.
F.16.	Spanish.
F.19.	Californian.
F.20.	Syrian, Beyrout.
F.20*b*.	Do.
F.24.	Yerli—Smyrna.
F.32*a*1.	Mid-West American.
F.32*a*2.	Do.
F.32*bx*.	Do.
F.34.	Plate.
F.35.	Mexican.
F.37.	North African—Tripoli.
F.38*a*.	Danubian.
F.38*b*.	Do.
F.39*a*.	Yerli—Smyrna.
F.41.	Marmora.
F.42.	Ouchak.
F.43.	Gaza.
F.46.	Cyprus.
F.48.	Russian—Ghenigesk.
F.49.	Do. Ozov.
F.50.	Bessarabian.
F.77.	Himalayan Hooded (Trifurcatum).
F.80.	Black, H., Vulgare.
F.83*b*.	Do. Distichum.
F.84*c*.	Zeocrithum.
F.91*b*.	Persian Gulf.
F.91*c*1.	Do.
F.91*c*2.	Do.
F.93*a*1.	Do.
F.97.	Beaven's Hexastichum. (Selected 1896).
F.98*a*.	Chilian.
F.100.	Servian.
F.102.	Indian—Karachi.
F.103.	Do. Calcutta.
F.110.	Oregon, White.
F.111.	Indian.
F.112.	Oregon, Dayton Blue Brewing.
F.113.	Persian Gulf—Karoon.
F.116.	Egyptian.
F.119.	Mesopotamia, R.3.
F.120.	Do. R.4.
F.121.	Do. R.5.
F.123.	Do. R.7.
F.124.	Do. R.12.

F.127. Plate.
F.128. Mosul, Black.
F.129. American, Goldleaf.
F.130. Persian—Karoon, P.9.
F.133. Polish, P.3.
F.138. Chilean.
F.139. Japanese.
F.140. Do.
F.141. Khyber Pass (× McMullen, 1925)
F.150. Karachi—Cawnpore District.
F.152. Do. Gidderbaka District.
F.154. Indian Agra District.
F.157. Do. P.4, Abohar District.
F.163. Do. P.2, Budhlada District.
F.169. Do. Short Root Latoli.
F.170*a*. Do. Long Root Latoli.
F.170*b*. Do. Long Root Latoli.
F.171. Do. Short Root Surmani.
F.173. Do. No. 1 Lyallpur, B.S.
F.176. Do. No. 5 Lyallpur, E.
F.177. Do. No. 6 Gujrat.
F.180*a*. Persian.
F.180*b*. Do.
F.182*a*. Do. Black.
F.182*b*2. Do. Black smooth awns.
F.183*a*. Do. Brown smooth awns.
F.184*a*. Plate × 'Isiropinas', 2-row.
F.184*c*. Do. do.
F.184*d*. Do. do.
F.186*a*. Black Sea.
F.186*b*. Do.
F.187*a*. Danube.
F.187*b*. Do.
F.187*d*. Do.
F.188. Ouchak, smooth awns.
F.189. Do.
F.190. Tunisan.
F.191. Benghazi.
F.192. Mogador—Morocco.
F.193. North African.
F.194. Australian Chevalier—1925.
F.195. Chilean—Brown × Izgled.
F.196. Do. Chevalier.
F.197. White Oregon.
F.199. Naked × Wembley.
F.200. Californian, Mariout × Univ. of California, 1924.
F.201. Oregon, Mariout × Univ. of California, 1924.
F.202. Club, Mariout × Horst, 1926.
F.203. Sacramento Barley × Horst, 1926.
F.204. Atlas × Horst, 1926.
F.205. Hero, 1924 × Horst, 1926.
F.206. Do. Riverside, 1925 × Horst, 1926.
F.207. Hero, C.I., 1286 × Horst, 1926. (Club Mariout × Lion), smooth awns.
F.208. Indian, No. 9, 6-row, Mianivali, Naked.
F.209. Indian, No. 11, 6-row, Gujarkhara, Naked.
F.210. Indian, No. 12, 6-row, Jhang, Black Naked.
F.211. Indian, No. 13, 6-row, Kuln, Naked.
F.212. Indian, No. 14, 2-row, Panipat, Naked.
F.213. Indian, No. 15, 2-row, Black Naked.
F.214. Black Mariout × Thorpe, 1926.
F.216. Hilla Barley.
F.217. Kenya Colony.
F.219. Gaza × Shawa, 'A'.
F.220*a*. Do. 'D'.
F.221. Gaza, 1928.
F.223. Indian, U.P., 1928.
F.224*a*. Egyptian Mariout, 2-row.
F.224*b*. Do. do. 6-row.
F.225. Do. do. 1928.
F.230. Indian, Benwar District.
F.232. Do. Punjab.
F.236. Do. Hathras District.
F.241. Iceland Barley.
F.242. Czechoslovakia, Zaza.
F.243. Hanna × Little Asia.
F.245*a*. White Hanna × Syria.
F.246. Syrian Hama.
F.247*a*. Do.
F.247*b*. Do.
F.249. Marmora—Halim.
F.250*a*. Do. Kezan.
F.250*b*. Do. Do.
F.251*a*. Do. Ismal.
F.251*b*. Do. Do.
F.252. Do. Rateb.
F.253. Do. Sodor.
F.254. Turkish.
F.256. Tunisan.
F.257. Morocco.
F.259*a*. New Russian.
F.259*b*. Do.
F.259*c*. Do.
F.260. New Zealand.
F.261. Australian Cape.
F.262*a*. Palestine.
F.262*b*. Do.
F.264. East African, Chevalier.
F.266*a*. Canadian Western, No. 3.
F.266*b*. Do. do. No. 3.
F.267*a*. Do. do. No. 4.
F.267*b*. Do. do. No. 4.
F.270*a*. Plate.
F.273*a*. Egyptian Beheri (Commercial Types).
F.273*b*.
F.273*c*.
F.273*d*.
F.274*a*. Egyptian Mariout (Commercial Types).

F.274*b*.
F.274*c*.
F.274*d*.
F.274*e*.
F.274*f*.
F.275. Black Skinless × Kenya, 1930.
F.276. Monul × Mr. B., 1931 (Late).
F.277. Iraq, 1931.
F.278. Australian Cape, 1931.
F.279*a*. 'Neils Franchen', Barley × Chili, 1931, Archer Type.
F.279*b*. 'Neils Franchen', Barley × Chili, 1931, Chevalier Type.
F.280. Karachi, 1932.
F.289. Do. 1936.
F.281. Chilean, No. 276.
F.282. Do. No. 257.
F.283. Do. No. 457.
F.284. Do. No. 287.
F.285. Do. No. 353/124.
F.286. Do. Sample 'A'.
F.287. Heavy Plate.
F.288. W. Australian Cape, 1935.

All parcels of Far Eastern barleys, as imported, are of many mixed races.

(6) *Established Varieties and Races*

These are two-rowed barleys (with the exception of one six-rowed from the Shetland Isles received in 1937) and they include Chevalier, Archer and Goldthorpe types, and hybrid races of more recent introduction to which common names have been given. Most of them are in cultivation in some parts of England, Scotland or Ireland. Some of these are certainly, and others are probably, 'synonyms', i.e. derived from the original same stock.

E.V.1. Early Welch.
E.V.2. Guld (Svalof).
E.V.3. Scotch Annat.
E.V.4. Do. Common.
E.V.5. Hanna.
E.V.6. Pryor's Australian Chevalier.
E.V.7. Webb's Kinver Chevalier.
E.V.8. Webb's New Universal Chevalier.
E.V.9. Webb's Golden Grain Chevalier.
E.V.10. Webb's Sunrise.
E.V.11. Do. B.
E.V.12. Halletts' Chevalier.
E.V.13. Golden Drop (D.21) (Old English Chevalier).
E.V.14. Chevalier.
E.V.15. Old Irish.
E.V.16. Nottingham Long Ear.
E.V.17. Old Wiltshire Archer.
E.V.18. Cannell Archer.
E.V.19. Beaven's English Archer.
E.V.20. Danish Archer (D.1) (Skanska selection).
E.V.21. Danish Archer (D.2) (Copenhagen selection).
E.V.22. Danish Archer (D.3) (Swedish Svalof).
E.V.23. Princess.
E.V.24. Brage.
E.V.25. Brewer's.
E.V.26. Millennium.
E.V.27. Victory.
E.V.28. Parker's Fortyfold.
E.V.29. Garton's 419.
E.V.30. Do. Abed Kenia.
E.V.31. Do. Regenerated Archer.
E.V.32. Do. Admiral Beatty.
E.V.33. Do. Triumphant.
E.V.34. Do. 1917.
E.V.35. Do. New Invincible.
E.V.36. Golden Pheasant.
E.V.37. Webb's Binder.
E.V.38. Do. Burton Malting.
E.V.39. Primus (Svalof).
E.V.40. Spratt (Warminster selection).
E.V.41. Goldthorpe.
E.V.42. Garton's Goldthorpe.
E.V.43. Plumage.
E.V.44. Garton's Plumage, No. 63.
E.V.45. Archer/Goldthorpe.
E.V.46. Standwell (Warminster selection).
E.V.47. Garton's Standwell.
E.V.48. Do. Maltster.
E.V.49. Probably 'Bere' (received from Shetland Isles, 1937).

BIBLIOGRAPHY

This corresponds with dates in brackets

ATTERBERG, ALBERT (1899). 'Die Varietäten und Formen der Gersten,' *Journ. Landw.*, xvii, 1–44.

BAKER, T. H. (1911). *Records of the Seasons. Prices of Agricultural Produce and Phenomena observed in the British Isles* (Simpkin, Marshall & Co., London).

BARBACKI and FISHER (1936). 'A Test of the Supposed Precision of Systematic Arrangements,' *Ann. Eugen.*, vii, pp. 189–193.

BEAVEN, E. S. (1902). 'Varieties of Barley,' *Journ. Fed. Inst. Brewing*, vii, No. 5.

—— (1909). 'Pedigree Seed Corn,' *Journ. Royal Agric. Soc. England*, lxx.

—— (1928). 'Appendix to a Study of the Comparative Yield of Barley Varieties with Different Manurings, by Gregory and Crowther,' *Annals of Botany*, xliii, No. 167.

BISHOP, L. R. (1930). 'The Nitrogen Content and Quality of Barley,' *Journ. Inst. Brewing*, vol. 36 (vol. 27 new series), p. 352.

BRENCHLEY, W. E. (1909). 'On the Strength and Development of the Grain of Wheat (*Triticum vulgare*),' *Annals of Botany*, vol. 23, pp. 117–139.

BROWN, A. J. (1900). 'Colouring Matter in Barley,' *Journ. Fed. Inst. Brewing*, vi, 480–488.

BROWN, H. T., and MORRIS, G. H. (1890). 'Researches on the Germination of the Gramineae,' *Journ. Chem. Soc.*, lxii, 459.

—— (1893). 'A Contribution to the Chemistry and Physiology of Foliage Leaves,' *Journ. Chem. Soc.*, lxiii, p. 604.

CATON-THOMPSON, C., and GARDNER, E. W. (1926). 'The Recent Geology and Neolithic Industry of the Northern Fayum Desert,' *Journ. Royal Anthropological Institute of Great Britain and Ireland*, lvi, pp. 301–323.

—— (1934). 'The Desert Fayum,' *Journ. Royal Anthropological Institute of Great Britain and Ireland*, sections 69–70, pp. 46–49.

COBBETT, W. (1885). *Rural Rides*, vol. 2 (Reeves & Turner, London).

De Vries, Hugo (1905). *Species and Varieties—their Origin by Mutation*, Lecture XVIII (Open Court Publishing Co., Chicago).

Engledow, F. L., and Yule, G. U. (1926). *The Principles and Practice of Yield Trials.* Empire Cotton Growing Corporation, London, vol. 3, Nos. 2 and 3.

Frazer, J. G. (1912). *The Golden Bough*, 'Spirits of the Corn and the Wild,' vol. i, chap. v, 3rd edition, pp. 131–132.

—— (1913). *The Golden Bough*, 'The Magic Art,' vol. i, p. x.

Gregory, F. G., and Crowther, F. A. (1928). 'Physiological Study of Varietal Differences in Plants. Part I. A Study of the Comparative Yield of Barley Varieties with Different Manurings,' *Annals of Botany*, vol. xlii, No. 167.

Harlan, H. (1918). 'The Identification of Varieties of Barley,' *U.S. Dept. Agric. Bur. Plant Industry Bul.*, 622, pp. 1–32.

Hulton, H. F. E. (1922). 'Relation of the Nitrogenous Matter in Barley to Brewing Values,' *Supplement to Journ. Inst. Brewing*, xxviii, 1, pp. 33–142.

Hunter, H. (1926). *The Barley Crop* (Ernest Benn, Ltd., London).

Jackson, A. (1933). Letter to *Nature* (London), May 6, vol. 131.

Johannsen, W. (1899). *Résumé du compte-rendu des travaux du laboratoire de Carlsberg* [Copenhagen], tome 4me, pp. 122–192. Abstract in *Brewing Trade Review*, November, p. 347.

—— (1903). *Ueber Erblichkeit in Populationen und in reinen Linien* (Gustav Fischer, Jena).

Körnicke, F. (1882). *Die Saatgerste, in der Zeitschrift für das gesammte Brauwesen.*

—— (1895). *Die hauptsächlichsten Formen der Saatgerste* (Bonn, Universitäts-Buchdrückerei von Carl Georgi).

Körnicke und Werner (1885). *Handbuch des Getreidebaues* (Berlin, Verlag von Paul Parey).

Lancaster, H. M. (1936). 'The Maltster's Materials and Methods,' *Journ. Inst. Brewing.*

Lawes and Gilbert (1857). 'On the Growth of Barley by Different Manures, continuously on the Same Land; and on the Position of the Crop in the Rotation,' *Journ. Royal Agric. Soc.*, xviii, p. 530.

LINNAEUS, (CARL VON LINNÉ) (1753). 'Hordeum,' *Species plantarum*, i, 84–85.

MERCER, W. B., and HALL, A. D. (1911). 'The Experimental Error of Yield Trials,' *Journ. Agric. Sci.*, iv, Part II.

MUNRO, J. M. H., and BEAVEN, E. S. (1897). 'Manurial Conditions affecting Malting Quality of English Barley,' *Journ. Royal Agric. Soc.*, viii, Part 2.

—— (1900). 'Various Conditions affecting the Malting Quality of Barley,' *Journ. Royal Agric. Soc.*, ii, Part 2.

PERCIVAL, J. (1921). *The Wheat Plant* (Duckworth).

—— (1936). *Agricultural Botany*, 8th ed., p. 506.

RIMPAU, W. (1891). *Landw. Jahrb. 20*, p. 354 (Berlin).

ROGERS, THOROLD (1866–1902). *History of Agriculture and Prices in England, 1259–1793* (Oxford).

RUSSELL, E. J., and BISHOP, L. R. (1933). *Journ. Inst. Brewing*, 39, 287.

SHAW, W. N. (1905). 'Seasons in the British Isles from 1878,' *Journ. Royal Statist. Soc.*

STAPLEDON, SIR R. G. (1935). *The Land: Now and To-morrow* (Faber and Faber, London).

STOPES, H. (1895). *Malt and Malting.*

'*Student*' (1911). Appendix to Mercer and Hall's paper—'The Experimental Error of Field Trials,' *Journ. Agric. Sci.*, iv (Cambridge University Press).

—— (1923). 'On Testing Varieties of Cereals, *Biometrika*, xv, Parts 3 and 4.

—— (1936). 'Co-operation in Large-scale Experiments,' *Supplement to Journ. Roy. Statist. Soc.*, iii.

—— (1936). Letter to *Nature* (London), 'The Half-drill Strip System,' cxxxviii, 5 December.

—— (1938). 'Comparison between Balanced and Random Arrangements of Field Plots,' *Biometrika*, xxix (Cambridge University Press).

VAVILOV, N. I. (1922). *Journ. of Genetics*, xii, pp. 67–69.

—— (1923). 'A Contribution to the Knowledge of Soft Wheats, *Bull. of Applied Botany and Plant Breeding, Leningrad*, vol. xiii, No. 1.

—— (1926). 'Studies on the Origin of Cultivated Plants,' *Bull. of Applied Botany and Plant Breeding, Leningrad*, vol. xvi, No. 2, p. 170.

VILMORIN, LOUIS DE (1852). *Note sur le création d'une nouvelle race de betterave à sucre.*

WIEBE, GUSTAV A. (1935). 'Variation and Correlation in Grain Yield amongst 1,500 Wheat Nursery Plots,' reprint from *Journ. of Agricultural Research*, vol. 50, No. 4 (Washington, D.C.), pp. 331–357, U.S. Govt. Printing Office.

WIGGANS, R. G. (1921). *A Classification of the Cultivated Varieties of Barley* (Ithaca, New York).

WILSON, JOHN (1859). *Our Farm Crops*, i, p. 20.

WOOD, T. B., and STRATTON, F. J. M. (1910). 'The Interpretation of Experimental Results,' *Journ. Agric. Sci.*, iii, Part 4, pp. 417–440.

ACKNOWLEDGEMENTS

In connection with this posthumous record of Dr. Beaven's work on barley, acknowledgements are made to those who have kindly assisted in one way or another.

For illustrations, statistics and other information provided, thanks are due to the British Museum, the Royal Anthropological Institute of Great Britain, the Ministry of Agriculture, the National Institute of Agricultural Botany; to Professor John Percival, late of Reading University, Dr. Hunter, late of the School of Agriculture, Cambridge, Mr. H. Wickham, of the Warminster Experimental Station; also to Mr. A. Jackson, Mr. H. M. Lancaster and Professor John Percival, who kindly undertook the tedious task of reading the typescript.

A great debt of gratitude is due to Mr. G. S. Phillpotts and to some of his colleagues (of the staff of Messrs. Arthur Guinness, Dublin), who have done an immense amount of statistical work in elaborating the data shown in the author's correlation table A. Mr. Phillpotts has also made valuable deductions and conclusions from the data and summarized the correlations and other statistical results.

Finally, thanks are given to Mr. L. R. Shildrick and Mr. J. F. Brown (the author's last pupil), for their invaluable assistance in proof-reading and final revision of this work.

FIG. 50.—The author with Mr. H. Wickham, and his grandson, Beaven Wood.

INDEX